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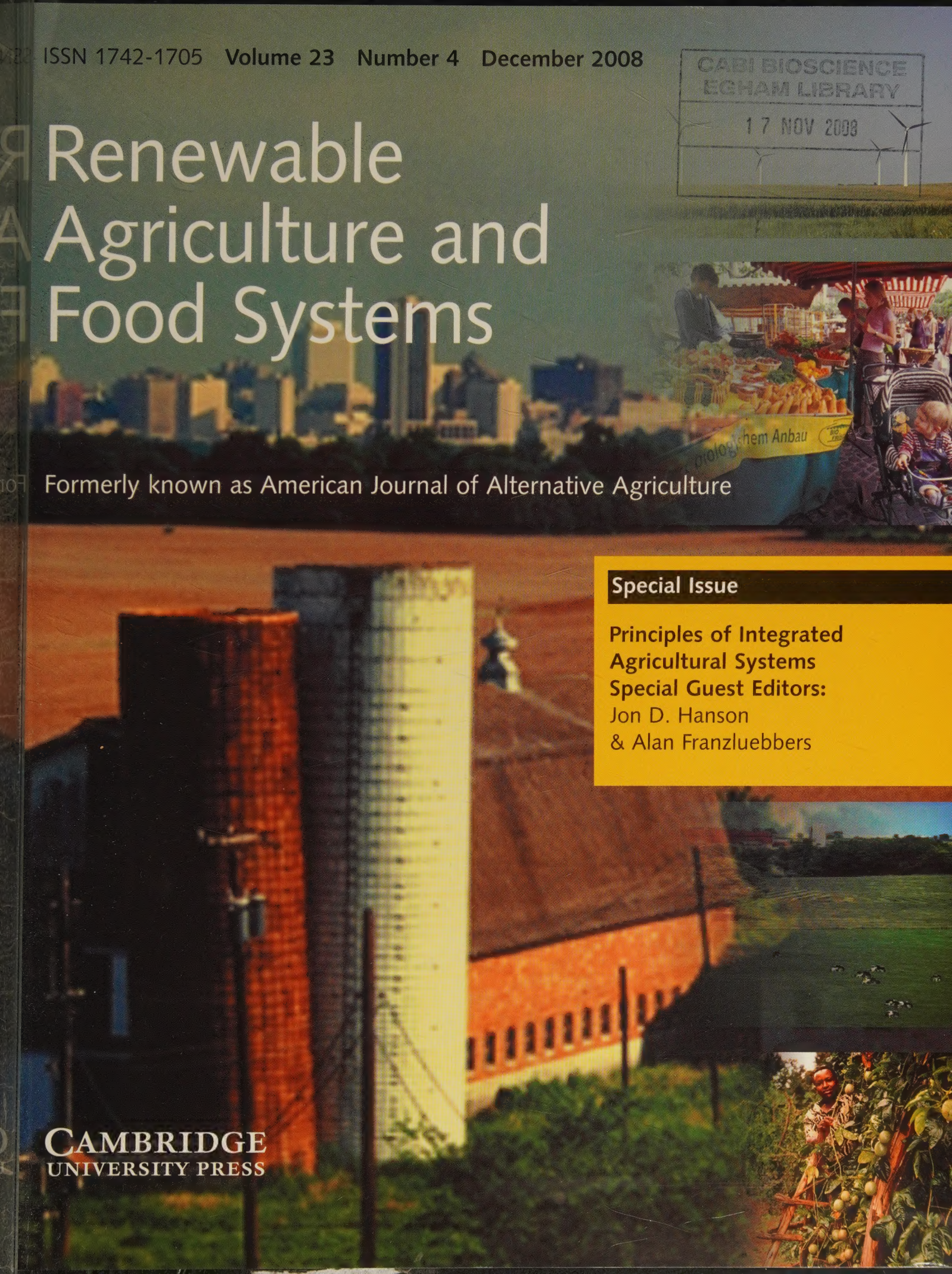

Special Issue

Principles of Integrated Agricultural Systems
Special Guest Editors:
Jon D. Hanson
& Alan Franzluebbers

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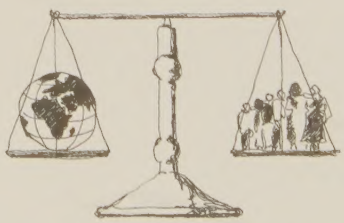

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Editorial

Principles of integrated agricultural systems

Rapid changes occurring in the agricultural environment are placing increased demands on producers. To respond to these demands, farmers need to manage their systems by reducing risk, while retaining management flexibility. Integrated agricultural systems have the potential to meet these objectives. Integrated agricultural systems are whole-farm strategies and technologies organized to help producers manage multiple enterprises in a synergistic manner to improve profitability and natural resource stewardship. In the past, American agriculture was focused solely on its ability to produce sufficient food, fuel and fiber to meet national and global demands. Agriculture has been largely successful in meeting these production demands. While productivity will continue to be a major factor in food production systems, increased societal demands for environmentally sound management, the need for rural community viability and a rapidly changing global marketplace are now shaping the evolution of more integrated and sustainable agricultural systems. In their efforts to help design and manage these systems, researchers need to be aware of the impact resulting from these external influences.

This special issue on 'Principles of Integrated Agricultural Systems' presents a hierarchical structure of agricultural systems, sets forth working definitions of these systems and describes their external influences. The goal for this special issue was to construct a framework to develop agricultural management systems that rely more on renewable resources, such as solar capture, biologically mediated nutrient cycling and pest control and crop–animal interactions, and less on non-renewable resources, such as fossil fuels and application of synthetic fertilizers and pesticides.

Principles of integrated agricultural systems need to be developed for several reasons. First, principles can be used to organize thinking. Understanding how a system is structured and how it functions is imperative when a system is investigated. Development of simulation models and decision support systems cannot be accomplished without first analyzing the fundamental processes controlling the system and defining how the processes are interrelated. Second, principles can be used to develop new management systems. Once the underlying principles of a system are understood, various functional components can be restructured to form new systems. Third, principles can be used to develop hypotheses to drive research. For example in the paper by Archer *et al.*, panelists identified research needs that could be expanded into researchable hypotheses, including (1) defining the relationship between agricultural policy and human health, (2) identifying the connection between obesity and the cost of healthy foods and (3) ascertaining whether the continual pressure on farms to become larger might be directly linked to vertical integration within the commercial sector. A set of guiding principles for integrated agricultural systems was initiated at a workshop held in Mandan, North Dakota, in 2004. This workshop in the northern Great Plains was the first in a series of workshops. Subsequent meetings were held in Alabama in 2005 and in Maine in 2008.

In this special issue, four general categories were used to describe the influences on agricultural systems: (1) social/political, (2) economic, (3) environmental and (4) technological. These papers suggest that the following critical issues must be addressed by agricultural managers, policy makers and researchers. First, sustainable systems must be flexible enough to respond to the future challenges facing agriculture. Second, newly emerging social and political factors include rising fuel costs, obesity, potential decreases in commodity subsidies, consumer awareness and demands to know how food is produced, and economic returns to land. Third, American agriculture operates in a market-driven economy that is impacted by policy, technology and environmental concerns. These factors in turn affect the scale of operation, while controlling management flexibility. Fourth, agricultural incentives control management decisions, often to the detriment of the environment. Integrated agricultural systems need to be developed that are adapted to the environment, rather than trying to adapt environmental constraints to the agricultural systems. Fifth, enhanced technology has increased the complexity of farming. Sixth, future agricultural systems must address emerging issues in land use, decline in work force and societal support of farming, global competition, changing social values in both taste and convenience of food, and increasing concerns for food safety and the environment. Seventh, a set of robust principles needs to be defined and subsequently used to design adaptable integrated agricultural systems.

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During the past several decades, several changes have occurred in the structure and operation of farm and ranch systems, thereby impacting the continued sustainability of American agriculture. These changes include a reduction in the number of farms and farmers, increases in farm size, and concomitantly the commercialization of farms. New policies must be developed to encourage the integration of agricultural systems. Farmers want to produce the most marketable and cost-effective products. Therefore, they logically choose to produce what they perceive as the 'best' commodities resulting in increasing specialization without much regard for the environment. Actively managing for multiple services can substantially reduce agriculture's environmental footprint and can be encouraged with production incentives that reward environmental stewardship. These incentives, whether trade-based or policy-based, must be tailored to forestall continued environmental degradation and loss of agricultural sustainability. Policies with adequate incentives must be provided for ecosystem services, such as clean water and air, productive and healthy soil, habitat development and restoration, and carbon sequestration and storage.

Current American agricultural systems are dramatically different from agricultural systems at the start of the 20th century. Economic, social/political, environmental and technological drivers have all interacted to shape the current agricultural domain. To understand the structure of future agricultural systems, an understanding of how drivers have affected current agricultural systems is needed. Highly specialized systems, such as commodity crop production and supply chain livestock production, appear most vulnerable to future changes. Future agricultural systems need to be developed to balance multiple goals and ensure sustainability. We believe that a dynamic set of integrated agriculture production principles and practices will allow producers the flexibility to achieve this balance. This special issue should help to stimulate further discussion on the topic and put forth a path towards developing and achieving agricultural sustainability.

Jon D. Hanson
USDA-ARS,
Northern Great Plains Research Laboratory,
1701, 10th Avenue, SW,
PO Box 459,
Mandan,
ND 58554, USA
jonhanson@ars.usda.gov

Alan Franzluebbers
USDA-ARS,
J. Phil Campbell Sr.
Natural Resource Conservation Center
1420, Experiment Station Road,
Watkinsville,
GA 30677, USA

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Principles of integrated agricultural systems: Introduction to processes and definition

John R. Hendrickson[1,*], J.D. Hanson[1], Donald L. Tanaka[1], and Gretchen Sassenrath[2]

[1]Northern Great Plains Research Laboratory, USDA-ARS, Box 459, Mandan, ND 58554, USA.
[2]Application and Production Technology Research Unit, Jamie Whitten Delta States Research Center, 141 Experiment Station Road, Stoneville, MS 38776, USA.
*Corresponding author: hendricj@mandan.ars.usda.gov

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Abstract

Agriculture has been very successful in addressing the food and fiber needs of today's world population. However, there are increasing concerns about the economic, environmental and social costs of this success. Integrated agricultural systems may provide a means to address these concerns while increasing sustainability. This paper reviews the potential for and challenges to integrated agricultural systems, evaluates different agricultural systems in a hierarchical systems framework, and provides definitions and examples for each of the systems. This paper also describes the concept of dynamic-integrated agricultural systems and calls for the development of principles to use in developing and researching integrated agricultural systems. The concepts in this paper have arisen from the first in a series of planned workshops to organize common principles, criteria and indicators across physiographic regions in integrated agricultural systems. Integrated agricultural systems have multiple enterprises that interact in space and time, resulting in a synergistic resource transfer among enterprises. Dynamic-integrated agricultural systems have multiple enterprises managed in a dynamic manner. The key difference between dynamic-integrated agricultural systems and integrated agricultural systems is in management philosophy. In an integrated agricultural system, management decisions, such as type and amount of commodities to produce, are predetermined. In a dynamic-integrated system, decisions are made at the most opportune time using the best available knowledge. We developed a hierarchical scheme for agricultural systems ranging from basic agricultural production systems, which are the simplest system with no resource flow between enterprises, to dynamic-integrated agricultural systems. As agricultural systems move up in the hierarchy, their complexity, amount of management needed, and sustainability also increases. A key aspect of sustainability is the ability to adapt to future challenges. We argue that sustainable systems need built-in flexibility to achieve this goal.

Key words: agricultural production systems, hierarchy, dynamic-integrated agricultural production systems

Introduction

Agriculture has successfully met the food and fiber needs of most of the world's population. World population has grown from 2.5 billion in 1950 to a projected 6.4 billion in 2005[1] and global average per capita food availability has risen from <2400 calories to >2700 calories[2]. This has been possible because cereal yields have increased by 150%, while land area in farms has remained relatively stable since 1950[3]. Today's agriculture uses only 0.2 ha of land per person[3]. However, agricultural producers are operating in an increasingly complex and rapidly changing environment. Besides the traditional focus on production, agricultural producers must also balance conflicting demands involving social, political, economic, technological and environmental issues.

Modern intensive agriculture alters the resource base and potentially reduces both its carrying capacity[4] and its sustainability[5,6]. In the Great Plains of the United States for example, many cropping systems are characterized by a lack of crop diversity[5] and declining soil organic carbon[7].

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At the same time, livestock production in the United States is based on efficiently converting feed grains into meat acceptable for human consumption, a system heavily dependent on fossil fuels[8].

Many small and mid-sized agricultural producers are concerned about economic sustainability of their farming operation. When farm income declines, government payments tend to increase to offset lower farm incomes[9]. Despite this buffering of farm income, farm numbers have continued to decline, especially among mid-size farms[10]. Seventy-two percent of the economic value of agricultural production now comes from large, very large and non-family farms[10]. Many small and medium sized farms rely on off-farm income. Average income from US farm-related activities ranged from 5 to 16% of the total farm income during 2001–2005, with the remainder coming from off-farm sources[11].

Integrated Agriculture

Full integration of agricultural systems at the producer or community scale may help in slowing or reversing some of the detrimental environmental and economic problems associated with specialized industrial agriculture. Modern agriculture requires intensive inputs. However, the use of forages and other diverse crops in the crop rotation can reduce intensive inputs[5,12,13], while in some cases increasing crop yield[12,14], enhancing nutrient cycling[5,13], reducing plant disease[15] and improving soil quality[7]. Integration of livestock and cropping systems has the potential benefits of enhancing nutrient cycling efficiency, adding value to grain crops, and providing a use for forages and crop residue[5]. Integrated crop/livestock producers traditionally have raised a greater diversity of crops, encouraging crop rotation[16] and have allowed livestock to convert low-quality crop residues or failed crops into higher value protein[17].

Integrated agricultural systems are not new. The number of commodities produced per farm has decreased from five in 1900 to approximately one in 2002[18]. Integrating forage, crop and livestock systems can spread economic and production risks over several different enterprises, thereby taking advantage of a variety of agricultural markets[5,7]. As an example, incorporating forages into a Canadian cropping system potentially reduced risk more than participation in government programs[12]. There are also potential environmental benefits to integrated systems. Research in Norway indicated that runoff of N and P was linked to the amount of ley in the system[19]. In New Zealand cropping systems, 2–4 years of grass-clover swards resulted in large net N input and increased soil aggregate stability, soil porosity, and earthworm activity. Soil properties rapidly declined during the subsequent 2–4 years of crop production[20].

Recently, some US producers have adopted more diversified management systems that include crops and livestock[7,21]. However, operators of integrated production systems face immense challenges, including labor availability and allocation, timing of operations, equipment considerations, and supply and market availability[22]. Even with economic risks spread over multiple enterprises, producers with integrated operations still require information on potential benefits and trade-offs to manage their enterprises successfully. Despite the advantages of integration, many farms in the Great Plains have increased crop diversity but have not fully integrated land use[7].

Challenges to Integrated Agricultural Systems

The complexity of today's agriculture forces producers to consider making decisions that meet multiple objectives (Fig. 1). A producer must set goals to define the endpoint towards which efforts will be directed. Agricultural producers must balance goals dealing with production, economic, social, political and environmental issues. Production goals involve producing the most appropriate crop or product under the resource and climatic regime in which they are operating. This is the most basic goal, since what is produced is usually considered directly proportional to the gross income received. However, economic goals and the interactions with other components of the system must also be considered. Pannell[23] showed the importance of accounting for farm-level interactions in evaluating lupin (*Lupinus angustifolius* L.) introduction to a Western Australian farm. By not incorporating the effects of lupins on nitrogen fixation, improved soil structure, reduced cereal disease levels, use as sheep feed and improved machinery efficiency, economic benefits from lupins would have been underestimated.

Producers must also consider the social ramifications of their decisions, not only for their own economic well-being but also on society as a whole. By 2007, it is projected that more people worldwide will live in urban environments than in rural areas[24]. This trend has already occurred in developed countries, resulting in fewer people with a direct connection to agriculture. However, the urban population still maintains its interest in how rural landscapes are managed[25]. Also, fewer farmers will impact the social communities in which they live and work because of their decreasing numbers.

Government farm policy can also influence management decisions. In the United States, farmers growing corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], wheat (*Triticum aestivum* L.), cotton (*Gossypium hirsutum* L.) and rice (*Oryza sativa* L.) received a majority of direct government payments[9], but payments only accounted for a fifth of total cash receipts in 2000[26]. Farm programs can influence land use and, to a lesser extent, the mix of crops planted[26]. Some farm programs, such as crop insurance and marketing loans, can increase production of certain commodities because of greater expected returns per unit of production[27]. Other farm programs, such as direct

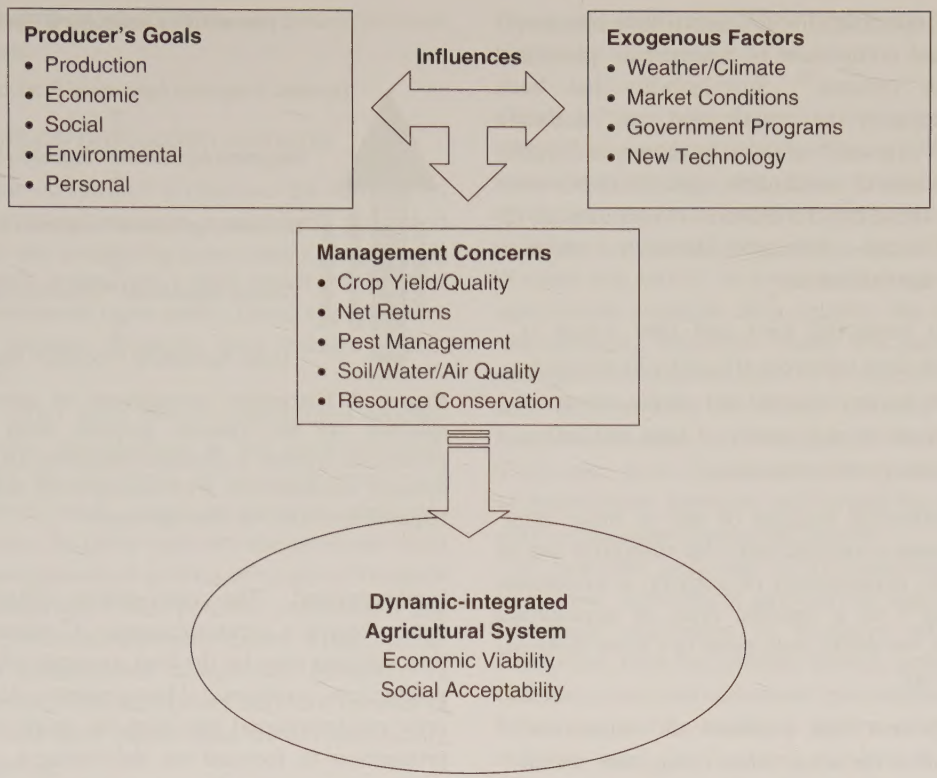

Figure 1. Producers in dynamic-integrated agricultural production systems must consider multiple criteria prior to making management decisions. These criteria and their relative importance influence producers' decisions. Adapted from Tanaka et al.[29].

payments and counter-cyclical payments, affect producer decision-making by increasing producer income and potentially their willingness to take risks[28]. However, by increasing income, these programs may also increase complacency among producers and reduce their incentive to try alternative approaches to agriculture. Producers need to consider the direct and indirect effects of government farm policy when they are making management decisions.

Finally, producers must consider the environment within which they operate. Uncontrollable issues further complicate the setting of goals by producers. Exogenous factors include weather/climate, market conditions, government programs and new technology (Fig. 1). These four external factors can do much to make or break an agricultural enterprise. By considering producer goals and the exogenous factors influencing agriculture, management systems can be developed to optimize such issues as product yield and quality, net enterprise return, pest (both insect and plant) management, soil, water and air quality, and resource conservation.

All of these issues, as well as rapidly changing technology, result in a complex and fluid environment in which agricultural producers must operate. Agricultural systems need to be developed that are sustainable and adaptable to change, but yet maintain their productivity. Therefore, we have developed a framework called 'dynamic-integrated agricultural systems' to achieve this goal.

Definitions

Tanaka et al.[29] described a concept called 'dynamic cropping systems' which provided an approach to cropping systems that producers could use to make sustainable crop production decisions. They described this concept as a long-term strategy of annual crop sequencing that would optimize crop and soil use options and the attainment of production, economic and resource conservation goals by using sound ecological principles. The dynamic aspect of this concept is a management philosophy that requires decisions to be made at the most opportune time with the best available information. A multi-directional information flow is an important component in decision-making. Key factors incorporated into decision-making in this system include diversity, adaptability, reduced input cost, multiple enterprise systems, awareness of appropriate information, and awareness of the environment. We extend this definition beyond cropping systems and incorporate aspects of it into a new concept called 'dynamic-integrated agricultural systems'.

To develop this framework, we must define some of the terms used to describe the different systems and approaches. We developed the philosophical concept for dynamic-integrated agricultural systems by evaluating and classifying other agricultural systems currently used in the northern Great Plains.

The concept of sustainability in agriculture has emerged as an important component of mainstream plant and animal production systems[30]. Sustainability has been considered the capacity to create, test and maintain adaptive capacity[31]. Lyson[32] noted that there are literally hundreds of definitions of sustainable agriculture but most definitions contain these key dimensions: (1) ecological, (2) economic and (3) social-community. Hence, we chose to define sustainable agriculture as:

> An approach to producing food and fiber which is profitable, uses on-farm resources efficiently to minimize adverse effects on the environment and people, preserves the natural productivity and quality of land and water, and sustains vibrant rural communities[33].

Agricultural production consists of one or more enterprises within the same economic unit. An enterprise can be a unit of economic organization or activity, a systematic purposeful activity[34] or a specific type of agricultural production[35]. Here, we define enterprise in a more systems-orientated manner as:

> A system component that produces an output and provides a resource for some other component within that system.

Agricultural producers combine one or more enterprises along with their management philosophy to form agricultural systems. These production systems can range in both structural and managerial complexity to form a hierarchy of production systems. In the next section, we define the more common production systems and their implications for complexity and sustainability.

Agricultural Systems

Figure 2 demonstrates the complexity of different agricultural systems, which are described below.

Basic agricultural production systems

These are the simplest, usually having no more than two enterprises. Enterprises in agricultural production systems have minimal interactions, i.e. resources do not flow from one enterprise to another.

Examples of an agricultural production system would be wheat–fallow, corn–soybean rotation, or confined animal production. In a wheat–fallow system, annual land use has been predetermined and a producer's management skills are focused on a single crop, i.e., wheat. Although water harvested in the fallow year is used by wheat, there is only one enterprise for the economic unit. In a corn–soybean rotation common in the US corn belt, both corn and soybean are planted and harvested within the same relative time period with similar equipment. The development of herbicide-tolerant varieties means weed management is comparable for both crops, and management is generally predetermined. The corn–cotton rotation in the US cotton belt is a similar example. Confined animal production systems may be the best example of basic agricultural production systems. Management decisions are not only predetermined but may be made off-farm, and the production is focused on delivering a single, consistent commodity to a food processor.

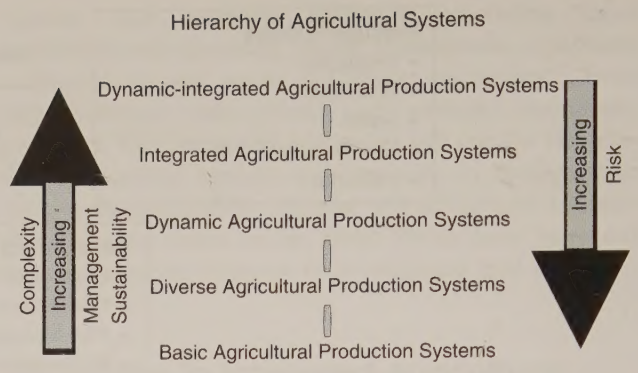

Figure 2. Hierarchial arrangement of agricultural production systems. As the systems progress from basic agricultural production systems to dynamic-integrated agricultural production systems, sustainability, system complexity and management input required increase, but risk decreases.

Diverse agricultural production systems

Diverse agricultural production systems contain three or more species of crops or livestock but strategic management of each enterprise is generally predetermined and follows a set of best management practices.

Examples of this type of system would be a fixed crop rotation or a crop–livestock farm in which interactions between the crop and livestock enterprises are limited, and the enterprises are managed in a predetermined manner. In both cases, management options such as land use or classes of livestock raised are predetermined, but structural and management complexity increases because the producer must consider management requirements of at least three crops or livestock.

There are examples of diverse agricultural production systems where producers may have other enterprises that are not specifically an additional crop or livestock species. One example would be a cotton farmer, who also owns, or is part-owner, of the cotton gin, warehouse and marketing association. The cotton produced on the farm would generate some revenue, and the ancillary enterprises (gin, warehouse and marketing association) would generate supplemental income. Another example is that of a catfish (*Ictalurus punctatus*) farmer, who owns or is part-owner of the catfish feed plant and catfish processing plant. These separate enterprises interact with the primary agricultural commodity—the catfish. While there is resource exchange in one direction (feed plant to catfish ponds to processing plant), the agricultural system is not

integrated as there is no feedback from one enterprise back to the preceding one.

Dynamic agricultural production systems

These rely on an annual strategy to optimize the outcome of production, economic and resource conservation goals and allow producers to use production components (crops, crop sequences, livestock types, etc.) that result in optimal production with minimum input costs. These systems have diversity in time because producers must manage externalities that change.

These systems differ from diverse agricultural production systems in that management is not predetermined. Rather, things such as crop types or livestock production systems are adjusted yearly, based on weather conditions and potential returns. In these systems, the producer must understand the management of a series of crops or livestock types as well as understand their potential returns and any implications of previous management history. These factors lead to increased management complexity. However, in these systems, the different enterprises may not interact in space and/or time and these interactions are not specifically considered in planning.

Integrated agricultural production systems

Integrated agricultural production systems are agricultural systems with multiple enterprises that interact in space and/or time and the interactions result in a synergistic resource transfer among enterprises.

These systems differ from dynamic agricultural production systems because there is interaction between different enterprises and the synergistic resource transfer between enterprises. An example of an integrated agricultural production system may be an integrated crop–livestock production unit where manure from livestock is added to crop land and at least a portion of the grain grown on the farm or the stover (crop residue) is fed to livestock. Manure from livestock can replace some of the fertilizer inputs[36]. Feeding grain to livestock or allowing them to use crop residues can potentially add value to the grain or crop residue[17]. A cotton farmer who uses gin trash from a ginning operation as organic matter input for cotton production would have an integrated system because there is a synergistic resource transfer. Similarly, a catfish farmer who uses products from a catfish processing plant as fertilizer to produce soybeans, which were then used in catfish feed, would make the catfish/crop production system integrated. These operations may also reduce economic risk through diversified marketing opportunities and avoidance of price cycles. These operations involve increased management, because of the need for understanding not only crop and livestock management but also their potential interactions. However, these operations may not be dynamic, in the sense that their management may be fixed rather than determined on an annual basis by considering all of the producer goals.

Dynamic-integrated agricultural production systems

These are agricultural production systems with multiple enterprises managed in a dynamic manner that interact in space and/or time and these interactions result in a synergistic resource transfer among enterprises.

While dynamic-integrated agricultural production systems are similar in structural complexity to integrated agricultural systems, they require the highest degree of management. Producers must not only understand the management requirements of a variety of enterprises but they need to also use annual planning to determine the best combination of enterprises for their operations. They also have to consider the potential ramifications of interactions between enterprises to determine how to obtain maximum synergistic benefit.

If livestock were one of the enterprises in a dynamic-integrated agricultural production system, it would add additional challenges to producer adoption. Livestock enterprises have to consider animal genetics, reproduction considerations and consistent feed supplies. They may also be constrained by having a portion of their land that can only be used for livestock production (i.e. rangelands). However, there may be ways for producers to incorporate a dynamic philosophy into their livestock operations. For example, cow–calf producers could keep a portion of their calf crop and either graze or sell them the subsequent year, depending on prices and precipitation. Other options may be to alter the livestock class or species in response to producer goals, exogenous factors and management concerns (Fig. 1). For example, producers with mixed livestock systems, such as cattle and sheep, may consider altering the proportion of cattle to sheep in their herds in response to better prices for either sheep or cattle.

As the hierarchy progresses, agricultural production systems have more enterprises and require more management input (Fig. 2). For example, a diverse agricultural production system where multiple crops are grown has more enterprises and requires more management input than simple agricultural systems such as wheat–fallow. Adding the dynamic management philosophy onto a diverse cropping system may not increase the number of enterprises but will increase the management requirements because decisions are not predetermined but made after considering multiple factors. A dynamic-integrated agricultural system is therefore the most complex system because multiple enterprises are considered and the interactions between enterprises and management decisions are not predetermined. However, this system should be the most adaptable system to respond to future agricultural challenges.

Besides the increase in complexity, both in structure and management needed, from a basic agricultural production system to a dynamic-integrated agricultural production system, we feel there is a corresponding increase in sustainability (Fig. 2). Sustainable agriculture

encompasses three dimensions; economical, environmental and social-community[32]. In dynamic systems, as defined by Tanaka et al.[29], all three of these dimensions are considered. In addition, as stated earlier, integrated agricultural systems can reduce the environmental impact of agriculture[5] and potentially lower risk for producers[5,7,12]. Also, as the hierarchy progresses, the inclusion of multiple enterprises should pose lower production and economic risks and an increase in adaptability. The maintenance of adaptive capacity[31] may be the greatest contributor to long-term sustainability.

We believe that risk decreases as the hierarchy progresses from a basic agricultural production system to a dynamic-integrated agricultural production system. Hardaker[37] defined risk as 'uncertainty of outcomes'. Agricultural producers are generally 'risk averse'[38]. The largest concern for many agricultural producers is income. Incorporating a variety of enterprises, using the best information available, and making decisions in a dynamic manner may give producers tools to reduce income uncertainty. Because sustainable agriculture implies a holistic, systems-oriented approach to agriculture that focuses on the interrelationships between environmental, social and economical factors[32], reducing the income uncertainty can enhance the sustainability of individual producers and may allow them to make decisions that will enhance social and environmental sustainability as well.

Factors Influencing Integrated Systems

Integrated agriculture has the potential to fully or partially address many of the problems that confront agriculture. Integrated agriculture can help increase agricultural diversity from the field to the farm scale, which may increase system stability[5]. Integrated agriculture may also be the best framework to use for developing sustainable agricultural systems. In Europe, an integrated approach to crop production called 'integrated farming systems' has been advocated as a sustainable approach to agriculture that can maintain farmer income and safeguard the environment[39]. Integrated agricultural systems are complex systems and developing and analyzing them can be difficult. The development of a set of principles underlying complex agricultural systems can assist in the difficult task of developing integrated agricultural systems.

Each of the described systems relies on principles to be successful. Principles have been described as 'the ultimate source or cause of something'[40]; 'advice, guidelines, prescriptions, condition–action statements, and rules'[41]; or 'guidelines or prescriptions for how to use intentions'[42]. These definitions range from highly definitive laws to loosely applied guidelines. We chose to define principles as:

> A set of concepts or ideas that help to explain how systems operate.

When looked at in this manner, even the simplest system relies on principles. For example, a wheat–fallow system is based on the principle that harvesting water and controlling weeds during the fallow year will enhance yields during the subsequent cropping year.

The first in a series of planned workshops to develop principles for integrated agricultural systems was held in Mandan, ND in November 2004. The objective of these workshops was to organize common principles, criteria, and indicators that exist across physiographic regions to provide insight into the management of integrated agricultural systems. At the first workshop, a series of factors influencing the development of agricultural systems was identified. These factors were diverse but mainly fell into four areas: (1) social/political, (2) economic, (3) environmental, and (4) technological. Following papers in this volume examine these drivers in detail. Understanding these factors is the first step in developing principles for integrated agricultural systems.

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Social and political influences on agricultural systems

David W. Archer[1,*], Julie Dawson[2], Urs P. Kreuter[3], Mary Hendrickson[4], and John M. Halloran[5]

[1]USDA-ARS, 803 Iowa Avenue, Morris, MN 56267, USA.
[2]Washington State University, Pullman, WA, USA.
[3]Texas A&M University, College Station, TX, USA.
[4]University of Missouri, Columbia, MO, USA.
[5]USDA-ARS, Orono, ME, USA.
*Corresponding author: archer@morris.ars.usda.gov

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Abstract

Agricultural systems are situated within social and political environments that have tremendous influence on how they operate. If agricultural systems are to be sustainable, it is critical to understand how they are influenced by social and political factors. An expert panel approach was used to identify and rank the importance of social and political factors on agricultural systems in the US and to provide some insights into their impacts, interactions and mechanisms of influence. The panel identified a wide range of social and political factors that affect agricultural systems. The factors were divided into three categories: internal social factors, external social factors and political factors. Factors from each of the three categories were highly ranked, indicating that no single category dominated the others. Although there were contrasting views about the importance of some factors, there was strong consensus about many of them. Globalization and low margins that require increased scale and efficiency were identified as the two most important factors affecting agricultural systems. Several newly emerging factors were identified as well as factors needing further research. A comprehensive understanding of these factors is imperative to help guide scientific research so that beneficial discoveries are accepted and used, and to ensure that policy decisions enhance the future sustainability of agricultural production.

Key words: social, political, agriculture, sustainability

Introduction

Agricultural systems do not operate in a vacuum. Rather, they are situated within social and political environments that influence the way in which they operate. Therefore, if agricultural systems are to be sustainable, it is critical to understand how they are influenced by the prevailing social and political environments. For researchers and extension educators involved with the physical and biological aspects of agricultural systems, understanding potential social and political influences may mean the difference between beneficial discoveries that are accepted and used and discoveries that, although potentially beneficial, are socially or politically unacceptable and are therefore not applied. For social scientists and policymakers, understanding social and political influences on agricultural systems may mean the difference between policies and social structures that improve social, economic and environmental sustainability, and those leading to disastrous consequences for agriculture and the environment. In identifying barriers to adoption of sustainable practices, the social, political and cultural context of agriculture has often been ignored[1]. Indeed, with regard to sustainability, the environmental and economic indicators are well established, but 'what is lacking is an awareness of the social issues'[2].

Most people involved with agriculture can identify social and political factors that have impacts on agricultural systems; however, there is a danger that some of the cause–consequence relationships are 'myths' or simplifications that miss the true underlying cause[3]. There is a need to increase awareness and develop consensus about the factors that have the greatest influence and for which the greatest research needs exist to improve sustainability of agricultural systems. The objective of this study was to identify and begin developing consensus on the most important social and political factors influencing agricultural systems in the US. The objective went beyond simply listing the most important factors by providing some insight into

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their impacts, interactions and mechanisms by which they influence agricultural system. This was part of a coordinated effort to identify (1) social/political, (2) economic, (3) environmental and (4) technological factors influencing agricultural systems as a first step towards developing a set of guiding principles for integrated agricultural systems. A similar framework was used as part of the Millennium Ecosystems Assessment, with the idea that 'understanding the factors that cause changes in ecosystems and ecosystem services is essential to designing interventions that capture positive impacts and minimize negative ones'[4]. With this study, we help advance the effort to better understand the factors that cause changes in agricultural systems by identifying and analyzing those factors that have the greatest impacts on agricultural systems. In the following section we provide a brief overview of the historical trends in US agriculture to provide the social and political setting for our analysis.

Historical Trends

As society changes with time, influences on agricultural systems also change. Therefore, any assessment of the social and political drivers affecting agricultural systems is time-specific, and should be seen in light of changes that have occurred. Many of these changes can be tied to demographic trends. In the US, farm population has dropped in absolute terms and as a percentage of the total population. From 1900 to 1990, the proportion of population living on a farm dropped from nearly 40 to <2%[5]. As a result, most of US society has little personal connection with agriculture. Population in rural areas has also shown a long-term decline[6], and although there is some evidence that rural population losses have stabilized[7], there are regional differences in this trend. From an economic standpoint, the number of farming-dependent counties has dramatically decreased in the past 50 years[8]. Even in places where rural populations have increased, the composition of these populations has changed. These areas have increasingly become homes for metro-area commuters and retirees, and those seeking recreational opportunities and natural amenities[7,9]. As a result, much of the rural population has little connection to production agriculture, and may have lifestyle expectations that conflict with agricultural production practices and the traditional rural way of life[7,10].

There have also been important demographic changes at the farm level. The average age of farm operators has steadily increased, from 50.3 in 1978 to 55.3 in 2002. In 2002, 26.2% of farm operators were over the normal retirement age of 65[11]. As the farm population continues to age, issues related to healthcare, retirement costs and transfer of the farm to future generations will become important influences on management decisions.

Over the past century, the structure of agriculture has changed dramatically. In 1900, half of US agricultural sales were accounted for by the largest 17% of farms, compared to the largest 2% of farms in 1997[12]. In addition, farms have become more specialized. In 1900, the average farm produced five different commodities, while by 2002, the number of commodities produced per farm was just over one[8]. Drastic changes have also occurred beyond the farm level. There has been a general trend of consolidation within the agricultural input, processing and retail markets. In 1998, the top four firms marketed 67% of corn seed, 46% of soybean seed and over 97% of cotton seed in the United States[13]. In specific processing industries, the top four firms marketed 90% of malt beverages in 1992 and 83% of beef packing in 2004[14]. By 2004, the top five food retailers accounted for 46% of retail food sales in the US[14].

Since the 1960s, agriculture has become more globalized and US agricultural exports have increased rapidly[8]. Interestingly, US is both the leading exporter and leading importer of agricultural products, and in recent years imports have increased at nearly twice the rate of exports[15]. This shift has tended to further separate the public from production agriculture.

World population continues to grow with increasing demands for food production and increasing pressure on natural resources. Cultivated systems now cover about 25% of the Earth's terrestrial surface[16]. Water withdrawals from lakes and rivers and flows of biologically available nitrogen in terrestrial ecosystems have doubled since 1960[16]. Yet, in 2004, 1.1 billion people were estimated to be hungry worldwide[17]. Within the next 50 years, demand for food crops is expected to grow by 70–85% and demand for water by 30–85%[16].

Ironically, in the face of chronic malnutrition and the challenge of feeding a growing population, the world faces an obesity epidemic. In 2000, over 1.1 billion people worldwide were estimated to be overweight with 300 million people classified as obese[18]. In US, the population is becoming heavier (35% of adults overweight and 30% obese[19]), especially among minorities and the poor[20]. Public concern about this trend could have a tremendous influence on food consumption and agricultural production.

Other demographic trends may also influence food consumption. The US population is aging, becoming more affluent and more ethnically diverse. These changes are anticipated to lead to increased demand for higher food quality, convenience and variety[21]. Although the US median household income has generally increased since 1967[22], inequalities in incomes have also increased since that time[23]. Diverging income levels between individuals within the US and between the US and other countries lead to differing social expectations for agricultural systems. A common perception is that affluent individuals have greater expectations for convenience and variety of foods, for scenic landscapes, for a clean and healthy environment, and for recreational opportunities to be provided by agricultural systems[24,25]. While limited-resource individuals may have these same desires, economic forces often mean they struggle to obtain enough calories, let alone nutritious foods and a safe environment.

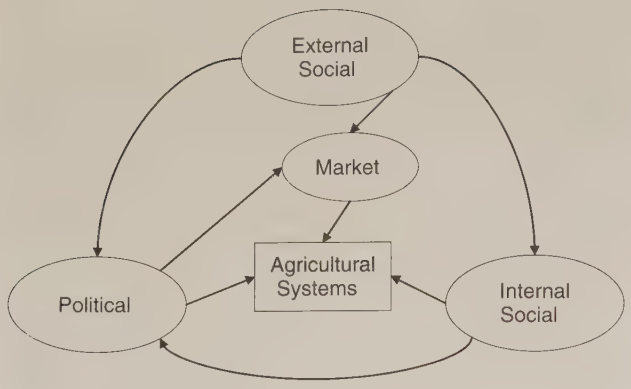

Figure 1. Social and political influences on agricultural systems.

These trends provide the relevant background for identifying the social and political factors influencing agricultural systems at this point in time. As will be shown, many of these trends have a direct connection to the factors that will be identified. Given this background, we now provide a conceptual framework for the analysis.

Conceptual Framework

Although the term 'agricultural systems' can pertain to a range of spatial scales, the farm level is the focus of this analysis as this is where production decisions are made. Farms are where social, economical and ecological factors interact most profoundly[26]. Also, because any assessment of the social and political factors influencing agriculture is time-specific, this assessment will be contemporary. Conceptually, it may be useful to group social and political influences on agriculture into three categories: external social factors (those originating outside of the farm), internal social factors (those originating within the farm) and political factors. This division allows for analysis of a wide range of factors, while keeping comparisons among factors tractable. The division between social and political factors occurs naturally along discipline lines. The division between internal and external social factors is consistent with Van Calker et al.[27] in identifying sustainability attributes in dairy farming and with Geist and Lambin[28] in analyzing the drivers of tropical deforestation. This division serves to distinguish between factors that are associated with individual farmer and farm household behavior; and general public attitudes, values and beliefs. These three categories of factors interact with agricultural systems in different ways (Figure 1). External social factors generally do not directly affect agricultural systems, but influence agricultural systems through internal social factors via social norms, through markets for agricultural products and through the political process. Internal social factors have a direct influence on agricultural systems as they are a part of the farmer's decision-making environment. Internal social factors may also indirectly influence agricultural systems as farmers participate in the political process. Political factors interact with agricultural systems both directly and indirectly. Direct political influences are experienced by farmers through associated regulations and definitions of property rights that constrain management options. Indirect political influences generally come through the markets via such mechanisms as subsidies for agricultural production or conservation measures, and through government investments in public infrastructure.

Although this framework describes useful linkages, it should be used with some caution. The danger in identifying a set of factors that influence agricultural systems is that they may be seen as factors that are not a part of the system and over which we have no control. It is important to note that these factors are not independent of the systems they influence. Analytical methods for this conceptual framework are described in the following section.

Methods

An expert panel approach, following the procedure outlined by Van Calker et al.[27], was used to identify and rank the importance of various social and political influences on agricultural systems. Van Calker et al.[29] developed this procedure as part of an effort to construct a multi-attribute utility function to evaluate the sustainability of Dutch dairy farming systems. This procedure was developed based on weight elicitation methods used in decision analysis[30,31]. In the Van Calker et al.[27] analysis, the expert panel approach was used initially as a tool for identifying and defining the relevant issues, and was designed to be universally applicable for other agricultural sectors, for other countries, and for other time periods. Our process included five steps: (1) panel selection, (2) questionnaire development by research project team, (3) expert panel completion of initial questionnaire, (4) compilation by research project team of factor list from expert panel, and (5) expert panel ranking of factors. The steps of the procedure were conducted sequentially as follows.

Panelists were selected in a two-stage process, first by compiling a list of recognized experts, then selecting a diverse subset of the qualified experts. For this analysis, the research project team decided to focus on academic experts within the agricultural social science field. It was recognized that other stakeholders such as farmers, industry representatives, consumers and members of environmental organizations would also be capable of assessing these factors. However, similar to Van Calker et al.[27], the decision was made, based on the judgment of the research team, that academicians would have the expertise needed to identify the most important social and political factors influencing agricultural systems. Since this group is well known for participatory research where they constantly interact with other stakeholder groups, it was expected that the views of these other stakeholder groups would be represented. The initial list of 30 recognized academic experts was compiled from the recommendations of the research project team, based on discussion of their stature and competence related to the social and political aspects of

agricultural systems. A diverse subset of the recognized experts was then selectively extracted to represent a broad range of areas of expertise, scientific institutions and geographic experience. Again, this followed closely the Van Calker et al.[27] process in which competence was the main selection criterion for the experts, and panelists were selected from a range of scientific institutions. A panel size of nine was selected to provide a sufficient range of expertise, while keeping data collection and analysis manageable, and allowing a greater breadth of information to be collected from each panelist versus collecting a more superficial level of information from a larger group of panelists. A key objective of this project was to go beyond compiling a list of important factors and to gather insights into the mechanisms by which these factors might influence agricultural systems. The research team recognized that the small panel size might have reduced the validity of the ranking results; however, it was deemed that the more detailed insights gathered in this manner would be more valuable to social scientists, policymakers and others. This panel size was comparable to the 7–10 panelists used by Van Calker et al.[27]. The panel was selected to include three rural sociologists, three agricultural economists, and three other agricultural and food systems experts.

Using the three conceptual categories of external social factors, internal social factors and political factors, an initial list of factors for each category was developed by the research project team to provide the expert panel with a starting point. The initial list of factors was included in the questionnaire sent to the panelists. The panelists could then add or remove items from the list of factors under each category. In addition to simply identifying factors, the panelists were asked to provide reasoning on why specific factors were added to or removed from the list. They were also asked to identify newly emerging factors and factors for which there were critical research needs. After sending the questionnaires to the panelists, they were contacted by telephone to answer any questions they might have about the survey. They were also given the opportunity to decline participation at this point. If the panelist declined to participate, an alternate panelist was contacted. After the questionnaires were returned, the panelists were contacted by telephone a second time to discuss their responses in more detail.

Responses from each of the panelists were compiled into a single list of factors under each subdivision: external social, internal social and political. The consolidated list of factors was then sent back to the panelists for ranking. Again following Van Calker et al.[27], two ranking procedures were used to allow testing for internal consistency. In the first ranking procedure, *ordinal ranking*, the panelists were asked to select the five most important factors in each category, and then to rank them from highest to lowest in terms of importance, with 5 being the most important factor and 1 being the least important factor of the top five. Factors that were not included among the top five were assigned a numerical value of zero. In the second ranking procedure, *interval ranking*, panelists were asked to rate all of the factors using a Likert-type scale of 1 to 5, with 1 being not an important factor at all and 5 being an extremely important factor. To facilitate comparisons between ranking procedures, relative importance weights W_{ij}, for each factor i, were calculated within each category and ranking method for each respondent:

$$W_{ij} = \frac{X_{ij}}{\bar{X}_j}.$$

Within each category and ranking method, X_{ij} is the numerical ranking value of factor i for respondent j, and $\bar{X}_j$ is the average ranking value of all factors for respondent j. Relative importance weights less than (greater than) one indicate factors with a ranking lower (higher) than the average ranking given by that respondent within that category. The Spearman rank correlation test was used with the relative importance weights to test the internal consistency of responses for each panelist. Again following Van Calker et al.[27], correlations not significantly greater than zero ($\alpha = 0.05$) were judged to be inconsistent and that panelist's responses were excluded from further analysis within that category.

Table 1 shows the factors that were initially presented to the panelists and the final list after including the panelists' recommendations. Although some of the panelists recommended removing some of the factors from the initial list, no factor was suggested for removal by more than three panelists, so all of the factors were left on the final list for ranking. They were initially presented with 11 external social factors, seven internal social factors and seven political factors. They added five external social factors, ten internal social factors and five political factors. Among the external social factors, factors C and D were initially presented as one, but were sub-divided at the recommendation of the panelists.

Results and Discussion

Panelist response rate and consistency

Even with the small panel size, intensive follow-up and replacing panelists who declined to participate, the response rate was <100%. Seven of the panelists completed the initial questionnaire and follow-up telephone interview. The eighth panelist indicated willingness to participate, but never completed the questionnaire. The ninth panelist declined to participate and three additional panelists were contacted sequentially as replacements; however, each of them declined as well. By this time, nearly a month had passed since the initial panelists had completed their surveys, and it was decided to proceed with the ranking portion while the topic was still on the minds of the remaining seven panelists. However, only six of those panelists completed the ranking questionnaire. These included two economists, two sociologists and two other

Table 1. List of most important external social factors, internal social factors and political factors affecting agricultural systems.

ID	External social factors	Internal social factors	Political factors
A.	*Meeting food and nutritional needs of growing population*[1]	*Aging farm operators*	*Farm Bill commodity programs*
B.	*Environmental concerns*	*Farm worker safety/health*	*Farm Bill conservation programs*
C.	*Consumer demand for low prices*	*Landowner perspectives of threats to property rights*	*Federally funded agricultural research*
D.	*Consumer demand for convenience*	*Resistance to adoption of novel technology*	*International trade policy*
E.	*Consumer demand for taste/variety/ quality*	*Legal liability concerns*	*Food safety regulations*
F.	*Opposition to genetically modified organisms (GMOs)*	*Lack of opportunities for beginning farmers and ranchers*	*Environmental regulations, e.g., Clean Water Act, Endangered Species Act, etc.*
G.	*Desire for locally produced foods*	*Management style*	*Federal budget constraints related to discretionary spending and budget deficits*
H.	*Food safety concerns*	Management skills	Energy policy
I.	*Meeting demands of affluent consumers*	Rising fuel prices	Food industry influence on dietary guidelines process, food and agriculture policy
J.	*Meeting needs of limited-resource families*	Entrance of young people into agriculture who see importance of strong connection to consumers	Distorting food and agricultural policies
K.	*Fair trade/labor concerns*	Farm income stabilization	Federal mandate for school wellness policies
L.	*Market concentration/consolidation*	Risk management/resistance to risk	Rural development programs (value added, rural infrastructure programs, etc.)
M.	Increasing rate of obesity, continued high incidence of heart disease and cancers	Fear of regulation	
N.	Food marketing far outweighing nutrition education	Returns to land	
O.	Rural community development	Intense competition for land and resources	
P.	Commodity organizations	Low margins that require increased scale and efficiency	
Q.	Returns to land	Globalization	

[1] Factors in *italics* were among those initially presented to the panelists.

agricultural and food systems experts, so the even representation of the three groups was maintained.

Within each category, internal consistency of responses between the two ranking procedures was checked for each panelist and for all panelists together (Table 2). Correlations for all panelists within each category showed that responses were consistent overall. Rankings for political factors showed the highest level of internal consistency (0.75 versus 0.68 for external social factors and 0.64 for internal social factors). Individual responses were also generally consistent with the exceptions of the internal social driver rankings for panelist E, and the political driver rankings for panelist B. The extreme lack of consistency among political driver ranking responses for panelist B was explained by the difficulty this panelist had in deciding importance among factors. Under interval ranking, this panelist gave all but one of the factors a score of 5, while

Table 2. Internal consistency of panelists.

	Correlation coefficients		
Panelist	External social factors	Internal social factors	Political factors
A	0.73*	0.76*	0.83*
B	0.58*	0.58*	0.24
C	0.80*	0.86*	0.84*
D	0.70*	0.79*	0.72*
E	0.65*	0.38	0.86*
F	0.68*	0.72*	0.78*
All	0.68*	0.64*	0.75*

* The association between ranking methods is significantly different from zero ($P < 0.05$).

Table 3. Average and standard deviation of relative importance weights for external social factors using interval ranking and ordinal ranking procedures.

		Interval ranking		Ordinal ranking	
External social factors	***N***	**Average importance weight**	**Std. dev. importance weight**	**Average importance weight**	**Std. dev. importance weight**
Market concentration/consolidation	6	1.30	0.25	1.51	2.23
Environmental concerns	6	1.25	0.19	3.97	2.00
Food safety concerns	6	1.17	0.31	1.51	1.71
Consumer demand for taste/variety/ quality	5	1.14	0.40	1.13	1.90
Food marketing far outweighing nutrition education	6	1.10	0.15	1.13	1.90
Increasing rate of obesity, continued high incidence of heart disease and cancers	6	1.09	0.27	1.32	1.67
Consumer demand for low prices	6	1.08	0.36	1.13	2.27
Consumer demand for convenience	6	1.05	0.47	0.76	1.85
Commodity organizations	6	0.98	0.44	1.70	2.66
Meeting food and nutritional needs of growing population	6	0.97	0.45	0.19	0.46
Desire for locally produced foods	6	0.94	0.27	0.00	0.00
Rural community development	6	0.88	0.40	0.57	0.95
Meeting demands of affluent consumers	6	0.87	0.19	0.00	0.00
Fair trade/labor concerns	6	0.83	0.32	0.57	1.39
Opposition to GMOs	6	0.81	0.14	0.00	0.00
Returns to land	6	0.80	0.29	0.00	0.00
Meeting needs of limited resource families	6	0.78	0.41	1.51	2.34

the panelist was forced to choose among factors under ordinal ranking. Ranking responses for these panelists were excluded from further analysis within these categories.

External social factors

The average relative importance ranking values for external social factors are shown in Table 3 in descending order of the interval ranking procedure average importance weights. Standard deviations of importance weights under interval ranking were generally low. Standard deviations of importance weights tended to be higher using ordinal ranking than under interval ranking. This is not surprising since the ordinal ranking process was designed to produce separation among the scores given to each factor with all but the top five given scores of zero. Although rankings of external social factors were shown to have an acceptable level of internal consistency, there were differences in the ranking order of the factors depending on the ranking method used. Ordinal data provide a valid method for checking internal consistency for each respondent, but the ranking process does not provide a measure of the strength of preferences between choices[32], and caution should be used in interpreting the average importance weights under ordinal ranking[33]. Thus, greater confidence should be placed on the interval rankings.

Interval ranking of the external social factors showed market concentration/consolidation and environmental concerns as the top two factors. Using ordinal ranking, panelists ranked environmental concerns as the most important factor but they made few comments about why this was an important factor. One panelist commented that environmental problems are more visible and people are more aware of the issues now than in the past, with the implication that this increased awareness will affect agricultural systems. This panelist also identified an important linkage between environmental concerns and the aging of farm operators internal social factor, indicating that, if there is a need to shift towards more ecologically based agriculture due to environmental concerns, it will be necessary to have people 'living in local ecologies long enough and intimately enough to learn how to manage farms well from an ecologically restorative perspective'. There is growing concern with the environmental costs of agricultural production[34]. However, there is also some evidence that the concept of multi-functionality is gaining acceptance in the US. There is a realization that agricultural enterprises can provide goods and services that society demands beyond food and fiber, such as improved water quality, wildlife habitat, landscape amenities, flood control, nutrient cycling and carbon sinks[35]. There is also evidence that social demands for these attributes are higher in more populated areas[36] and that they increase with increasing

incomes[25]. Some have envisioned an agriculture where farmers are primarily managers of rural landscapes and only secondarily as producers of food and fiber[37]. Economic evidence shows this might not be unreasonable as the income elasticity of demand for environmental quality may be greater than that for food in the United States, suggesting that as incomes increase, consumers' demand for environmental quality may grow faster than their demand for food[25].

Market concentration/consolidation was also included among the top five factors under ordinal ranking. Panelists agreed that market concentration/consolidation 'has been a powerful driver shaping the realities of production agriculture'. One panelist thought the influence of this driver may be changing, indicating that 'the wealth concentration that this consolidation has created is now becoming increasingly dysfunctional and the need for wealth expansion will likely be one of the significant drivers of the future'. Wealth concentration may not provide the same returns to financial institutions as having capital distributed among more entities, so these institutions will not see an economic advantage to continue concentrating capital. A second panelist saw the emergence of a dualistic agriculture with 'continual pressure on some kinds of firms to get large and become integrated upward to the industrial buyer' while there is an increasing opportunity 'for niche/boutique producers to serve a more astute and demanding consumer'. This panelist identified these two areas as topics needing further research. Another panelist identified a linkage among market concentration/consolidation, desire for locally produced foods, and food safety concerns. Concentration, rather than local, more diffuse production, may lead to a higher risk of targeted contamination or major disruption of food supplies.

The issue of vertical integration from the farm upward is the latest incarnation in the continuing tension between farming as a business and farming as a way of life, which one panelist commented, 'has been around forever'. In a recent discussion with Alabama chicken producers who produce under rigid integrator contracts, there was great frustration expressed about the loss of independence that had once been part of their way of life. One producer commented, 'We are slaves on our own farms!' Yet, one factor that appears to perpetuate the system is a continuing influx of people who are looking to get into farming for lifestyle reasons and see contract chicken farming as an easy way to get into farming because of the systems of available credit and management control that support contract poultry production[38].

Concern over food safety was also among the top five factors under both ranking methods. One panelist indicated, 'Food scares make people more aware of where food comes from and the risks of the current system'. This is particularly evident in the UK where a series of crises in agriculture and food production has been seen as a violation of a social contract and has led to a distrust of regulatory authorities and a more critical eye towards technology[39]. Two of the panelists described this factor in broad terms indicating it was related to how food is produced, including the desire for locally produced foods, consumer demand for taste/variety/quality, meeting the demands of affluent consumers, fair trade/labor concerns, and opposition to genetically modified organisms (GMOs). One panelist described safety with a small 's', saying people do not feel desperately threatened (by chemicals, GMOs, etc.) but they just do not want it. 'I want my food grown differently'. As another panelist put it, this contrasts with the industry notion of food safety being reduced to a set of standards that 'further industrialize the process of producing food'. Another panelist added, 'certainly not everyone wants to be an active participant in the food system;' however, 'there is a growing dissatisfaction with the status quo, a desire to know where food is produced and how it got to them'. One panelist identified this as an emerging factor, indicating there is a growing concern of civil society regarding issues 'like consumer demands to know how food is produced, their desire for locally produced food, and their concern for labor'. This is reflected in tremendous growth in direct sales of food to consumers and the growing evidence that local exchange of foods provides health, food-security, and well-being benefits for people, communities, and ecological systems. However, there is a danger that local direct sales of foods can create a premium market for wealthy clientele rather than democratizing the economy[40].

Increasing rate of obesity, and continued high incidence of heart disease and cancers were ranked sixth under both ranking methods. This was identified as an emerging driver by two of the panelists, both of whom indicated there was rising concern about this health crisis, and a need to understand how the current food system contributes to the problem. Emphasizing the magnitude of the problem, one of these panelists predicted 'that the anti-GMO issues will be overcome by the anti-obesity issues in industrialized agricultural production'.

Meeting the needs of limited resource families was among the top five factors using ordinal ranking while it ranked lowest using interval ranking. Standard deviations of importance weights were high for this factor under both ranking processes, indicating widely differing views among panelists. Two panelists selected this factor as second in priority, while none of the remaining panelists included the factor among the top five. One of the panelists who ranked this factor highly indicated that the issues of meeting the needs of limited resource families, meeting the food and nutritional needs of a growing population, and meeting the needs of affluent consumers were all interrelated. 'The kind of poverty that continues to make it impossible to keep populations fed despite over production simply will not be tolerated in a world that is now a global village with world-wide communications systems. Consequently the demand to develop a food system that provides healthy, nutritious, good tasting food at affordable prices for all of the planet's citizens will be a major driver shaping the food systems of the future'.

Table 4. Average and standard deviation of relative importance weights for internal social factors using interval ranking and ordinal ranking procedures.

		Interval ranking		Ordinal ranking	
Internal social factors	***N***	**Average importance weight**	**Std. dev. importance weight**	**Average importance weight**	**Std. dev. importance weight**
Globalization	5	1.38	0.29	2.49	2.58
Low margins that require increased scale and efficiency	5	1.37	0.33	2.49	1.48
Risk management/resistance to risk	5	1.21	0.43	1.59	2.21
Rising fuel prices	5	1.04	0.35	2.49	2.58
Aging farm operators	5	1.02	0.39	0.91	1.48
Management skills	5	1.00	0.31	1.13	2.53
Farm income stabilization	5	0.99	0.19	1.36	1.48
Intense competition for land and resources	5	0.98	0.22	1.13	2.53
Returns to land	5	0.97	0.38	0.68	1.01
Farm worker safety/health	5	0.93	0.15	0.00	0.00
Entrance of young people into agriculture who see importance of strong connection to consumers	5	0.93	0.31	0.68	1.52
Lack of opportunities for beginning farmers and ranchers	5	0.91	0.37	0.91	2.03
Management style	5	0.91	0.57	1.13	2.53
Legal liability concerns	5	0.87	0.09	0.00	0.00
Fear of regulation	5	0.87	0.24	0.00	0.00
Resistance to adoption of novel technology	5	0.83	0.25	0.00	0.00
Landowner perspectives of threats to property rights	5	0.78	0.22	0.00	0.00

Internal social factors

Our intent was to categorize social factors originating outside the farm as external and those originating inside the farm as internal. However, it appears that the panelists interpreted this division differently, classifying external social factors as those having an influence beyond the farm level and internal social factors as those having an influence at the farm level. Although the panelists indicated factors appearing on the initial internal factors list were important, once they had an opportunity to add additional factors and rank them, none of the initial factors were included among the top-ranked factors. Globalization, low margins that require increased scale and efficiency, risk management/resistance to risk, and rising fuel prices were included among the top four factors under both ranking procedures (Table 4). It was unexpected that globalization would be identified as a top internal social factor and not as an important external social factor. This may reflect a sense among the panelists that US farmers are acutely aware of the effects of globalization at the farm level. As one panelist indicated, 'US farmers are increasingly competing in a global agricultural market. This means they will have to produce competitively with farmers elsewhere in the world but it also means growth in the potential markets for their products'. The effect of globalization was also seen from a different perspective. Another panelist observed that many people see globalization as a form of tyranny, and as such, may be on the verge of collapse. There has been an ongoing debate regarding the current and future ability of globalization to improve economic well being and lead to free societies versus impinging on the rights of countries for self-determination, including protection of the environment and protection of its citizens from health risks. This debate is at the core of the issue of free trade and the ability of countries to restrict the importation of genetically modified food products. To some, the restriction is seen as a type of protectionism that reduces opportunities for farmers to market their products abroad and, therefore, suppresses economic growth and reduces food availability to the poor[41,42]. However, others question whether farmers and the poor actually benefit from free trade[43]. Some see these restrictions as a means for consumer and environmental protection, and contend that free trade rules interfere with a basic right of people to determine what they put in their collective mouths[44]. US farmers have an acute interest in this issue, as evidenced by news reports in the popular farm press[45].

Low margins requiring increased scale was among the top two internal social factors under both ranking

procedures. One panelist commented that increased scale and efficiency were important if a producer wishes to farm full-time. 'Its the race for technology, allowing farms to get bigger, (and) driving down costs ...'. This 'technology treadmill' is an often identified phenomenon in agricultural economics literature[46] that leads to increasing reliance on off-farm income[47], decreasing farm numbers, and increasing farm size[48]. Farmers feel the need to adopt new technologies at an early stage in order to survive economically. In the US, agriculture has suffered from this treadmill for over a century[49], and it has been argued that farmers need to be able to get off the technology treadmill in order to be truly sustainable[50]. The technology treadmill has also been shown to have a direct economic connection to returns to land, which was identified as a newly emerging external social factor. In the original treadmill theory, farmers adopt new technologies to drive down their cost of production and improve their incomes. However, this leads to increased production, driving prices (and profits) down. The theory was revised to include the impact of government price supports. In the presence of government price supports, prices are not driven down. Instead, farmers try to expand profits by acquiring more land, which drives up land prices. Therefore, farmers who rent land must adopt new technology to generate enough revenue to pay higher land rents, while farmers who own land must either adopt new technology or they can quit farming and rent their land to other farmers[48]. The challenge in getting off of the treadmill is finding other alternatives besides acquiring new technology, getting bigger or getting out. Options that have been proposed include increasing farmer bargaining power through collective action[51], and a movement towards smaller, more flexible and intensively managed farms that are able to fill niche markets[50]. In addition to the economic aspects of this factor, one panelist commented that competition for land within a local community can lead to deterioration in community relationships as neighbors are pitted against one another.

Rising fuel cost was identified as a newly emerging driver among the top internal social factors that may affect agricultural systems in several ways. One panelist indicated that, 'Fuel costs will be a driver in the adoption of energy-saving production practices as well as strengthening support for local food systems to reduce the distance between consumers and producers. The driver might also provide support for the rebuilding of value-added enterprises in areas where they have been lost'. Another panelist stated that rising fuel cost would lead agricultural production to rely more on biological synergies rather than energy inputs and increase the movement towards use of agricultural products for energy production.

Aging farm operators was ranked fifth under interval ranking and among the top ten under ordinal ranking. Two panelists made a connection between this factor and lack of opportunities for beginning farmers and ranchers. However, they had contrasting views about the magnitude of the problem, with one panelist indicating that there were many aging farm operators who would be willing to rent their land, but not to outsiders. 'Thus, there are a lot of opportunities for beginning farmers within the community, particularly if they have the right social networks to access it'. The other panelist indicated that persistent low profits in agriculture have 'prevented retiring farmers from setting aside funds for their own retirement, and so less of the farm's assets can be transferred to the next generation'.

Political factors

Farm Bill commodity programs were the highest ranked factor under both interval ranking and ordinal ranking (Table 5). Using interval ranking, all but one of the panelists gave Farm Bill commodity programs a ranking of 5 or 'extremely important'. Most of the panelists made comments related to this factor. Two of them drew a connection between commodity programs and one of the external social drivers, 'increasing rate of obesity, continued high incidence of heart disease and cancers'. One of these panelists indicated that current commodity programs 'perpetuate an overabundance of cheap commodities that the food industry can use to create high fat, high sugar, and nutrient-poor food products'. It has been hypothesized that there is a connection between obesity and the low cost per unit of energy for refined grains, sugars and fats compared to more healthy alternatives[21]. This connection may be especially strong for people with low incomes who may choose these foods simply because they are the cheapest sources of dietary energy[21]. The connection between obesity and the cost of healthy foods was identified by one of the panelists as an area needing further research. Also, both panelists identified the connection between commodity programs and obesity as an area that is poorly understood and would merit extra attention by researchers and policymakers, and they proposed that a better understanding of the interconnections between these factors may lead to policies targeted towards growing healthier food at the farm level.

These panelists also raised concerns about the influence of food industry and commodity organizations on current agricultural policy. Food industry influence on the dietary guidelines process, food and agricultural policy was ranked among the top five political factors under both ranking systems, and commodity organizations were the second most important external social factor under ordinal ranking.

Two panelists commented on the effect of Farm Bill commodity programs in influencing the decision about what crop to plant. Both indicated that the current program is a disincentive for farmers to try new crops or production methods, and one of them related this to the risk management/resistance to risk, identified as an internal social factor. This panelist lamented that Farm Bill commodity programs discount the value of alternative risk management methods, such as diversification into other crops. This is supported by recent research findings

Table 5. Average and standard deviation of relative importance weights for political factors using interval ranking and ordinal ranking procedures.

		Interval ranking		Ordinal ranking	
Political factors	***N***	**Average importance weight**	**Std. dev. importance weight**	**Average importance weight**	**Std. dev. importance weight**
Farm Bill commodity programs	5	1.29	0.46	2.72	1.84
Environmental regulations (e.g., Clean Water Act, Endangered Species Act, etc.)	5	1.19	0.34	1.12	0.91
Food industry influence on dietary guidelines process, food and agriculture policy	5	1.17	0.28	0.96	1.04
International trade policy	5	1.16	0.40	2.08	1.56
Federal budget constraints related to discretionary spending and budget deficits	5	1.09	0.35	0.32	0.72
Distorting food and agricultural policies	5	1.04	0.23	1.92	1.84
Farm Bill conservation programs	5	1.00	0.26	0.80	1.79
Energy policy	5	0.95	0.30	0.96	1.31
Rural development programs (value added, rural infrastructure programs, etc.)	5	0.89	0.27	0.80	1.39
Food safety regulations	5	0.78	0.44	0.00	0.00
Federally funded agricultural research	5	0.76	0.43	0.32	0.72
Federal mandate for school wellness policies	5	0.68	0.07	0.00	0.00

indicating that the value of crop diversification as a risk management tool is reduced when farmers can utilize commodity programs and crop insurance[52]. The panelist indicated that this was an area needing further research. Several panelists indicated that commodity program payments may decrease in the future due to federal budget constraints and international trade pressures, but one panelist was skeptical that budget constraints would lower commodity payments because 'the constraints are always balanced by well-entrenched vested interests'.

Environmental regulation was the second ranked factor under interval ranking and the fourth ranked factor under ordinal ranking. Only one panelist commented on this driver, relating it to Farm Bill conservation programs. This panelist indicated that Farm Bill conservation programs were not strictly oriented towards conservation, but were ways to indirectly support commodity programs by helping farmers comply with environmental regulations. This comment was primarily in regard to the use of conservation programs to fund manure management practices and facilities for confined animal feeding operations. Advocates of this use see it as a way to reduce the economic burden on farmers for complying with the regulations that require them to adopt these practices and build these facilities. However, many in the sustainable agriculture community see this as a corruption of the program's intent, paying for conservation measures that would occur anyway, providing incentives for larger livestock operations, and taking resources away from other conservation priorities.

Although rural development programs were near the bottom of the rankings for political factors, one panelist indicated that these may become more important in the future as the non-farm rural population increases, and their political power increases relative to the farm population. This panelist indicated that the needs of limited-resource farmers and the rural poor were areas needing a renewed research focus.

Overall factor rankings

The interval ranking process used a consistent ranking scale across all categories of factors. This allowed comparison among factors independent of category. In order to compare responses among categories, raw ranking scores were used rather than relative importance weights which were normalized within each category. Also, using raw ranking scores showed the importance the panelists placed on these factors. Based on average interval ranking scores, the top ten factors included a mix of external social, internal social and political factors (Table 6), indicating that no single category of factors dominated the others in influencing agricultural systems. The top ten factors all had average interval ranking scores of at least 4.0 on a scale from 1 to 5. The internal social factors: globalization and low margins

Table 6. Factors with the ten highest average interval ranking scores.

Category[1]	Factor	*N*	Average interval ranking	Std. dev. interval ranking
IS	Low margins that require increased scale and efficiency	5	4.6	0.89
IS	Globalization	5	4.6	0.55
ES	Market concentration/consolidation	6	4.5	0.84
P	Farm Bill commodity programs	5	4.4	1.34
ES	Environmental concerns	6	4.3	0.82
P	Environmental regulations (e.g., Clean Water Act, Endangered Species Act, etc.)	5	4.2	1.30
ES	Food safety concerns	6	4.0	0.63
IS	Risk management/resistance to risk	5	4.0	1.00
P	International trade policy	5	4.0	1.22
P	Food industry influence on dietary guidelines process, food and agriculture policy	5	4.0	0.50

[1] IS = internal social factor, ES = external social factor, P = political factor.

that require increased scale and efficiency were the top two factors overall.

Conclusion

A wide range of social and political factors affect agricultural systems. Insights provided by a diverse group of academic experts in the areas of agricultural economics, rural sociology and agriculture and food systems identified factors they considered to be particularly important influences on agricultural systems. This analysis utilized a limited sample size in order to gather more in-depth information from each of the participants and thus gain a broader understanding of how these factors are perceived to affect agricultural systems. The research project team deemed a small panel would be capable of identifying the most important factors without loss of generality. The low standard deviations of importance weights (using the interval ranking procedure) provided some support for this assumption. Nonetheless, because the sample size was limited, and panelists were limited to academic experts, it will be important to verify that these findings reflect the views of a larger population and differing segments of society (e.g., farmers, consumers and policymakers).

Although there were contrasting views about the importance of some factors, there was strong consensus about many of them. Rankings of the most important factors produced no major surprises, except that globalization was identified as an internal social factor. Presumably this reflected how acutely globalization affects decisions at the farm level. In addition to identifying and ranking the most important factors, panelists provided information on the reasoning behind their selections, and identified factors that were newly emerging or for which there were critical research needs. Newly emerging factors identified by the panelists included rising fuel costs, obesity, potential decreases in commodity subsidies due to budget constraints or trade rulings, consumer awareness and demands to know how food is produced, and economic returns to land. Research needs identified by the panelists included the relationship between agricultural policy and health, risk behavior on the farm, the connections between obesity and the cost of healthy foods, the needs of limited resource farmers and the rural poor, the continual pressure on farms to become larger and more integrated towards the industrial buyer, and the opportunity for niche/boutique producers to serve more discriminating consumers.

For physical and biological scientists, this information will help confirm or deny preconceived notions and improve awareness of social and political factors that impact the relevance of their research. For example, while most scientists involved in cropping systems research might recognize that rising fuel costs could generate interest by farmers in energy saving production technologies like reducing tillage or using legumes in place of purchased nitrogen, many would not have considered the potential that demand for locally produced foods may increase due to increased transportation costs, and that opportunities to diversify crop rotations may be driven more by increasing fuel costs than by risk management concerns. In addition, the linkages among many of the factors have not received a lot of attention in the cropping systems or animal science journals. Yet, these linkages, such as panelists' concern about obesity and its link to an industrialized food system, could be a very important area of study for natural scientists since these health concerns have the ability to impact markets for agricultural products and government policies.

Although most social scientists and policymakers may have a good general understanding of the most important social and political influences on agricultural systems,

the newly emerging factors and research needs identified in this study outline priority research topics and testable hypotheses. A comprehensive understanding of these factors is imperative to help guide scientific research so that beneficial discoveries are accepted and used, and to ensure that policy decisions enhance the future sustainability of agricultural production. By identifying the most important factors, providing supporting insights into their effects, and delineating emerging issues and research needs, this study provides a basis upon which a comprehensive understanding of these factors may be built.

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Technology, complexity and change in agricultural production systems

G.F. Sassenrath[1,*], P. Heilman[2], E. Luschei[3], G.L. Bennett[4], G. Fitzgerald[5], P. Klesius[6], W. Tracy[3], J.R. Williford[1], and P.V. Zimba[7]

[1]USDA-ARS Application and Production Technology Research Unit, PO Box 36, Stoneville, MS 38776, USA.
[2]USDA-ARS, 2000 E. Allen Rd., Tucson, AZ 85719, USA.
[3]Department of Agronomy, 1575 Linden Rd., University of Wisconsin, Madison, WI 53706, USA.
[4]USDA-ARS US Meat Animal Research Center, PO Box 166, Clay Center, NE 68933, USA.
[5]Department of Primary Industries, Private Bag 260, Natimuk Rd., Horsham, VIC 3401, Australia.
[6]USDA-ARS Aquatic Animal Health Research Laboratory, PO Box 952, Auburn, AL 36830, USA.
[7]USDA-ARS National Warmwater Aquaculture Center, Stoneville, MS 38776, USA.
*Corresponding author: Gretchen.Sassenrath@ars.usda.gov

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Abstract

Technological advances have contributed to impressive yield gains and have greatly altered US agriculture. Selective breeding and directed molecular techniques address biological shortcomings of plants and animals and overcome environmental limitations. Improvements in mechanization, particularly of power sources and harvest equipment, reduce labor requirements and increase productivity and worker safety. Conservation systems, often designed to overcome problems introduced from other technologies, reduce negative impacts on soil and water and improve the environmental sustainability of production systems. Advances in information systems, largely developed in other disciplines and adapted to agriculture, are only beginning to impact US production practices. This paper is the fourth in the series of manuscripts exploring drivers of US agricultural systems. While development of technology is still largely driven by a need to address a problem, adoption is closely linked with other drivers of agricultural systems, most notably social, political and economic. Here, we explore the processes of innovation and adoption of technologies and how they have shaped agriculture. Technologies have increased yield and net output, and have also resulted in decreased control by producers, increased intensification, specialization and complexity of production, greater dependence on non-renewable resources, increased production inputs and hence decreased return, and an enhanced reliance on future technology. Future technologies will need to address emerging issues in land use, decline in work force and societal support of farming, global competition, changing social values in both taste and convenience of food, and increasing concerns for food safety and the environment. The challenge for farmers and researchers is to address these issues and develop technologies that balance the needs of producers with the expectations of society and create economically and environmentally sustainable production systems.

Key words: technology, sustainability, technological drivers, genetic improvements, mechanization, conservation systems, information systems

Introduction

The 20th century's unprecedented advances in the application of biological science and engineering to agriculture have revolutionized farming. Technologies are implicitly functional, benefiting society by solving a problem or circumventing a functional constraint. Agricultural technologies include both engineering and biological inventions and discoveries, such as modifications to machinery, the physical environment or biological components of a system. Knowledge systems, such as decision support tools and management systems, are examples of cultural technologies.

The intensification of agriculture over the past 50 years has resulted in impressive yield improvements[1]. In the US, yields have risen steadily, with corn yields roughly tripling and wheat and soybean yields approximately doubling over the past half-century (Fig. 1a)[2]. Similar gains in animal production have increased egg production in chickens by 18% in the past 16 years, milk production

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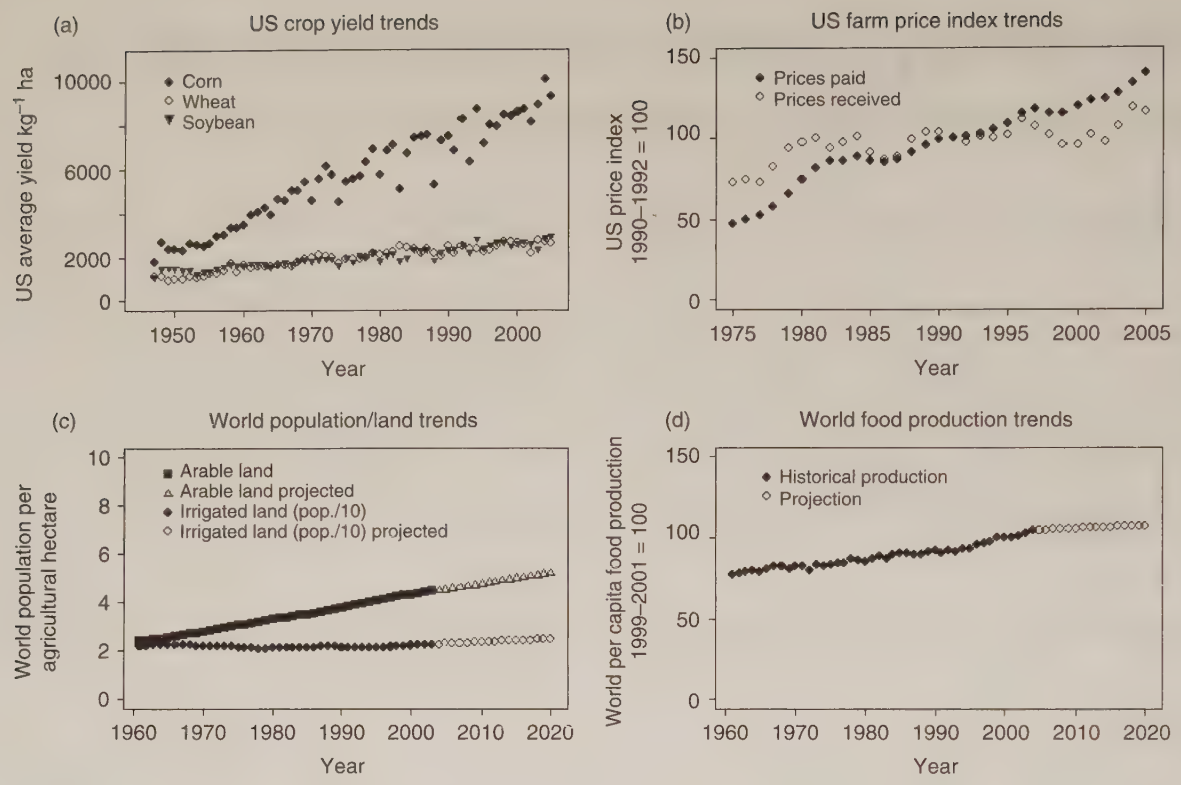

Figure 1. Historical and projected trends in agriculture.

in cows by 28% in the past 10 years, and average live broiler chicken weight by 155% in the past 80 years[3].

While addressing concerns of a growing world-wide population, these impressive yield gains have come at a cost to natural resources[4] and the farming community[5]. Capital intensive technologies required to realize these gains can favor agribusiness over family farms[5]. The continued development of new technologies, at times needed to address issues introduced from adoption of previous technologies, puts farmers on a technology treadmill[6] that limits their flexibility in making management decisions. Globalization has increased competition and generated new problems and opportunities. Current technologies have opened a proverbial Pandora's Box of opportunities, risks and hope for future developments.

In this manuscript, we explore how the technological revolution has altered American agriculture and how it is likely to contribute to changes in future production practices. We examine the traditional development and adoption cycle, and explore new models of innovation delivery that are changing the process of technological advancement. Our premise is that as the world population and agricultural productivity move towards sustainability, agricultural problems will become more difficult to solve with strategies focused solely on increasing yield potential. Agricultural productivity will need to shift from a simplistic focus on yield per hectare to incorporate a broader, interdependent set of constraints including all inputs to the production cycle: natural resources, financial and human resources[4]. We explore five fundamental ways that technology has impacted farming: (1) increased intensification of production, (2) increased reliance on natural resources, particularly soil and water, and non-renewable resources, primarily fossil fuels, (3) increased production inputs and dependence on future technology, leading to a technology treadmill that limits choices, (4) increased complexity of the farming system, and (5) decreased control by producers. These trends in agriculture have led to declining support for agricultural production as fewer people are directly involved with farming; increased degradation of natural resources through contamination of soil, water and atmosphere; depletion of natural resources, particularly water and fossil fuels; and decreasing profit margins. To address the interconnected constraints facing American agriculture and ensure future advances in agricultural productivity, multidisciplinary problem solving approaches will become increasingly important.

Processes of innovation and adoption

The problems and needs of the production community drive the interdependent processes of development and adoption to bring an innovation into use. Rather than a linear event, these two processes occur in a continuous spiral, with continued adaptation and modification of a technology furthering the advancement and continuing the cycle[7].

The traditional processes of technology development and adoption have been described as a linear or 'Push'

system[8,9] in which the problem is identified and technology developed for delivery to the end user. This method works well during crisis conditions, such as invasive pests or diseases (e.g. Karnal–Bundt and avian flu), or for problems requiring a high input of technical expertise or capital, such as development of genetic modification techniques.

Emerging models of development and adoption rely on closer interaction between technical developers and non-technical end-users. In a 'learning selection' model, developers interact closely with a self-selected group of interested end-users, and use their knowledge base to refine the initial design concept to the needs of the user group[8]. As the development–adoption process continues, the initial user group becomes invested in the technology and plays a key role in the dissemination of the information and adoption of the technology by a larger user group. This model works well in the development and delivery of mechanized agricultural technology, such as harvesting equipment[8]. In the 'Pull' model[9], a platform for information exchange is established that expands the base of knowledge available to the developers and end-users by bringing together large groups of diverse individuals to solve or influence a problem. Complexity and chaos are seen as opportunities for expansion of ideas rather than as negative factors that need to be controlled. This emerging model is operating in media, global process networks and education. The 'Pull' model holds particular promise for the large, complex problems, ranging from social to technical, that face today's agriculture. Expansion of the knowledge base, through increased participation of people from a diversity of disciplines, has the potential to enhance the creativity applied to solve emerging agricultural production issues.

The process of adoption is driven by interactions between a broad range of external and internal factors, such as political readiness, social and political pressure and monetary constraints[10]. Farmers have a desire for increased profitability and greater lifestyle security[5,11]. Competition from global markets has also facilitated adoption of new technologies as farmers recognize the need to remain competitive[12]. Innovations that reduce production risk and are relatively simple to use are most successfully adopted[13]. In addition, farmers who have ready access to an expert are much more likely to implement new technologies[14].

Problems driving innovation

Fundamental limitations to agricultural production arise from edaphic, abiotic and biotic constraints of the natural environment. Water has a particular global significance[15], and limits production in many areas due to quantity and quality constraints, as well as pumping costs. The biological capacity of crops and animals also limits yield. Natural resource limitations are critical to current and future production, and future impacts of global warming and climate change are of increasing concern to farmers. Additionally, the availability and expense of fossil fuels has become a concern as they are needed both as fuel for tractors and for fertilizer production.

Social and political pressures alter the expectations from agriculture[5]. Changes in the social conscience moved society towards the industrial model of success based on production output. Simultaneously, growing awareness of inequities in food availability encouraged aggressive production goals to increase the worldwide per capita caloric uptake[16]. To increase production levels with a declining pool of laborers for farm work, farmers needed to do more work with fewer people[17]. Legislation impacts major decisions through set-aside programs or price supports and the adoption of specific technologies directly, such as the 1996 Food Quality Protection Act[18]. The current discussion of environmental credits versus commodity payments will further impact farmers' decisions as to which production systems to implement[5,19]. Human resource limitations in management expertise and time further hinder productive capacity, requiring improved marketing and management skills to remain competitive.

Technological Advances

Genetic improvements

Advances in our understanding of reproductive biology and the mechanisms of inheritance enhanced our ability to make directed changes in crop and animal traits, improve yield, address environmental limitations, and overcome a host of production constraints. Genetic manipulation by selective breeding or direct molecular techniques is an established method for improving productive capacity and the regional usefulness of crops. Other technologies, such as weed and insect control and resistance to or control of diseases, increase productivity by preventing indirect competitive losses.

Hybrid maize was one of the 20th century's major scientific innovations contributing to yield improvements, and is widely cited as one of the most rapidly adopted agricultural technologies in the 20th century[20,21]. In addition to the yield advantages with hybrid crops, the greater crop uniformity increased the ease of management. Prior to the introduction of hybrids, a field of maize contained a mixture of unique genotypes varying in economically important traits such as ear height, maturity and grain characteristics. This variation made mechanization of production difficult, especially harvest. Mechanized harvesting of corn coincided with the adoption of hybrids[22]. Both improvements in yield and management hastened the adoption of hybrid technologies.

Though greater uniformity in the timing of plant developmental events may be desirable for timing of agricultural inputs and harvest, this uniformity renders the crops more susceptible to catastrophic losses from insects and pathogens. By compromising the seeds' natural defensive abilities by selecting for more desirable traits, producers must increasingly rely on chemical control methods and

increased management for some of the functionality that the crop once provided for itself. Extensive implementation of monoculture production has increased reliance on technologies such as chemical control methods and reduced crop diversity.

Hybrids have also instrumented a substantial paradigm shift in how society views genomic property rights, and played a role in the evolution of the seed industry. With hybrid technology, farmers must buy the seed each year rather than saving seed from the previous harvest. Competitors cannot sell a company's hybrids unless they obtain the rights. Development of hybrids and subsequent genetic modifications have removed natural genetic material from public ownership and placed it in the hands of a few companies[23]. As development and adoption of genetically altered materials increases, the production system becomes more complex. Moreover, producers increasingly lose control of their production decisions, as the management technology is genetically hard-wired in the seed[23].

The social response to genetic technologies is most apparent in the current debate over genetically modified organisms (GMOs)[24,25]. While opponents of the technology accuse agribusiness of profiteering at the expense of risks to public health, the purported harms of GMOs are often ascribed to political posturing and anti-science[26] by supporters of the technology. Regardless of one's support[25] or contempt[27] for the technology, it is obvious that it has had, and will continue to have, substantial social impacts[28].

As with plants, the natural genetic variations in animals have been used to selectively improve animal stocks. Until the mid-20th century, the formation of most modern breeds of livestock was defined by the breeders themselves and selection was strongly influenced by livestock competitions. Development of artificial insemination (AI) dramatically increased productivity, especially of dairy cows[29]. Combined academic and industrial research addressed a major constraint on genetic improvement through development of semen extenders, a method of freezing semen, and a convenient method of safely transporting frozen semen. Improved quantitation of genetic lineage has allowed managers and advisors to evaluate and benchmark their specific management strategies. Widespread dissemination of extended and frozen semen has resulted in international commerce of tens of millions of semen doses[30].

Formation of farmer-owned AI cooperatives and long- and short-term experiments conducted on cooperator farms were keys to the successful adoption of AI[29]. While these initial cooperatives were formed between producers, advances in AI technologies led to the consolidation of AI organizations and increased investment by privately held companies[31].

Modern gene manipulation tools have expanded our capacity for improvements and are used in animal and aquaculture systems to identify superior traits, enhance breeding programs, facilitate disease resistance and establish, meet and verify standards. Molecular genetics can be used to improve the population through identification of genes and genetic markers associated with a desired trait, such as disease resistance, improved growth rate or meat quality. Biotechnology in animal systems can be used to do the same things currently done through traditional breeding, but more quickly, more accurately, and (or) with a different price structure, thereby changing competitive advantages among individuals, companies and countries.

In the dairy industry, improved genetic evaluations for milk production led to rapid increases in milk production and a subsequent decline in the number of cows needed to sustain production levels. Mechanization and other improvements in dairy production intensified the consolidation of dairy farms. The reduction in nationwide herd size and consolidation of dairy farms has led to a reduced genetic diversity and increased inbreeding, which may be contributing to the recently observed reduction in fertility[31]. While genetic improvements of animals have increased performance and yield, as with crops, they have been associated with (a) a loss of farms through consolidation, (b) a decline in farmer control of the production process, and (c) an increased complexity of the farming system.

Mechanization

In the US, social pressures have driven the evolution of agriculture to deliver abundant, inexpensive, readily available foods year round. The changing social conscience introduced with industrialization shifted the social expectations away from farming as a way of life towards efficiency and production output[32]. Technological advances developed during and immediately after World War II increased mechanization and introduced chemicals to manage soil fertility and pests. Changes in commodity supports[10] and increased social pressure to feed the world further directed production towards large-scale monoculture agriculture[16]. While advances in biological and engineering technologies made large-scale monoculture production possible, changes in the social conscience made it desirable.

To address the social demands for food and expand production and improve yields, farmers needed easier, faster, less labor-intensive and more efficient means of managing crops. Mechanization of US agriculture during the 19th and 20th centuries began with the introduction of the tractor which removed much of the backbreaking toil, increased the speed, efficiency and amount of work that could be accomplished and improved worker safety[33]. Throughout the industrial revolution, innovations in farm machinery have dramatically decreased labor demands and improved the efficiency and effectiveness of field operations. The fraction of the population involved in agricultural production continues to decrease. Improved harvest, storage and transportation technologies have all contributed to greater efficiency and allowed feeding a growing population without substantial increases in land devoted to production agriculture.

A major benefit of mechanization is greater efficiency during the harvest operation which minimizes yield and

quality loss due to extended exposure to bad weather. Cotton (*Gossypium* sps., L.) has played a significant role in clothing humanity for centuries. Its technological advancement is often a leading sector indicating the level of industrialization of a country. Development of mechanical cotton harvesters substantially impacted the social and economic development of the cotton-growing regions of the US[34]. Cotton harvest technology continues to play a key role in modernization efforts in other societies[35].

While technical limitations hampered the development of mechanical cotton harvesters, social pressures of small farms and the sharecropping system stifled its adoption[36]. Many were fearful of the earliest mechanical pickers, envisioning the destruction of the South's sharecropping system and the loss of work for millions of people[37]. The major migration of 5 million people from the South for higher-paying jobs in the North between 1940 and 1960 led to a severe labor shortage[17]. While the initial adoption of the cotton picker was limited by concern for the prevailing socio-economic conditions at the time, a sharp decrease in available labor during and immediately after World War II became a major impetus for its acceptance[34].

The introduction of mechanization, particularly of harvest, increased the consolidation of fields and farms. The increased size and use of machinery introduced soil problems, such as compaction, and required greater management skill. The mechanization of cotton production increased the cost of machinery and farm operating overhead. Farm size increased to justify this outlay for machinery and to support the general farm overhead. The average cotton farm in the 1940s was about 320 ha, but by the 1970s the average size had increased to 600–800 ha, a trend that continues[17,38]. The harvesting operation had long been the decisive factor in land area one farm could manage, in cotton as well as other crops[39,40].

Additional improvements in mechanization have been realized through a host of highly effective technologies, such as fertilization, irrigation and tillage. These improvements modified the crop environment, minimizing the natural limitations of the crop and its environment. However, this increased reliance on mechanization also contributed to a greater dependence on fossil fuels, for both fuel and fertilizer, increased consolidation of farms, increased production inputs, overuse of natural resources and greater complexity of the farming system.

Lifestyle changes in the US have led to the increased consumption of convenience foods, impacting the food supply and altering agricultural production[41]. This led to the development of vertically integrated production systems, particularly of animals[10], and hastened the development of technologies supporting confinement animal production.

New barriers to production have been introduced through the intensification of animal production in confinement buildings and feedlots. Accurate identification and tracking of animals is needed to determine previous history and potential performance, and especially recognition of potential disease exposure such as bovine spongiform encephalopathy (BSE). As with monoculture crops, intensive animal production exposes animals to increased risks of some diseases, requiring changes in disease management including the increased use of antibiotics with uncertain impacts on consumers. Intensive animal production facilities also concentrate wastes which impair soil and water resources and require additional technologies to handle disposal. Moreover, the vertical integration of animal production, with its rigid top-down management and dependence on expensive animal production technologies, has left many producers frustrated from excess debt and a lack of control on their own farms[14].

Conservation technologies

While technologies addressing genetic improvements and mechanization are driven fundamentally by a desire to improve yield, the development of conservation production systems is driven by concerns for the environment, often resulting from problems introduced from previous technologies. Conservation practices help conserve limited soil and water resources and address production problems on areas too steep or dry for conventional tillage. Reduced tillage operations and use of cover crops protect the soil surface from erosion and ultimately increase organic matter and aggregate stability to improve the soil's water holding properties[42].

In addition to the environmental benefits, conservation technologies often approach agricultural production as a system. By considering the entire agro-ecosystem, the impact of production practices on the supporting natural resource base are recognized. As the knowledge of interactions within the agricultural production system grows, appreciation for the importance of conserving the natural resource base increases. Ancillary benefits to producers include savings in time and fuel from conservation tillage systems, as well as lower capital investment in powerful tractors and tillage equipment[43].

Conversely, conservation tillage has a number of potentially significant disadvantages. Tillage is an effective mechanical form of weed control that prepares the seed bed and reduces pathogens. Without mechanical weed control, herbicide use and costs will generally increase, especially during the early transition years. The introduction of herbicide-resistant crops hastened the adoption of conservation systems, as farmers had a reliable chemical method of weed control. However, this rapid and extensive adoption has increased the development of herbicide-resistant weeds[44]. Farmers are now on a treadmill of needing new herbicide-resistant varieties to compensate for failures in the previous technology.

Increased complexity of management results from the implementation of conservation systems, as timing of operations becomes more critical. Management of cover crop residue is also a concern. Increased residue from cover crops keeps the soil wetter and cooler after planting than

tilled soil, shortening the growing season. Increased residue from conservation tillage may also require changes in nitrogen management, as high levels of residue can immobilize nitrogen, limiting its availability near the seedling roots. Yield depression related to inadequate early season nitrogen may have been one of the causes for a dip in no-till use in the late 1990s[42].

Conservation technologies showed a combination of linear delivery and learning selection, with the public and private sectors providing the general outlines of the technology and farmers customizing and adapting the technology to their particular situations. Conservation tillage is adopted more rapidly by farmers with more education, larger operations, and higher incomes, and on farms with higher soil quality[45,46]. Risk-averse farmers adopt conservation tillage more slowly than risk neutral farmers to avoid higher initial costs while learning the new system[47]. Land tenure also influences adoption rates of conservation practices as cash-renters are less likely than owner-operators to adopt practices with medium term payoffs[14,48]. This may be a key finding for the future of American agriculture, as over 40% of US farmland is leased.

Perhaps the biggest boost for adoption of conservation tillage came from government programs, starting with the Conservation Compliance provisions of the 1985 Farm Bill, and continuing through subsequent farm bills. These provisions required farmers on Highly Erodible Land (HEL) to reduce erosion significantly by using an approved conservation system to maintain benefit and program eligibility. For many farmers on HEL, conservation tillage was the only feasible management system to maintain eligibility.

With continued pressure from environmental interests, social and political concerns and increasing fiscal demands, farmers will continue to explore methods to reduce costs by eliminating field operations, provided that options exist that maintain yields and profitability. With steadily improving implements, agrichemicals, and seeds adapted to higher residue levels, increased local experience, and declining social pressures against conservation tillage, conservation tillage should continue to expand, particularly where erosion is a problem, for larger, owner-operated farms and for farmers who are not strongly risk-averse. Improved methods of weed control, particularly if they are simple, would facilitate expanded use of conservation tillage for those crops and regions that have not seen much adoption to date. Modifications to future farm bills away from commodity payments towards conservation payments will likely further hasten the adoption of conservation systems.

Conservation systems have the potential to move agricultural production systems towards environmental sustainability. Environmental concerns will continue to influence governmental programs that promote conservation tillage. Baylis et al.[49] reported that even a moderate increase in adoption of conservation tillage would improve water quality enough to increase downstream recreation benefits nationally by $175 million. A large increase in the use of conservation tillage may contribute $243 million nationally for recreation alone.

Information systems

Information systems are examples of technologies that were largely developed in areas other than agriculture, and have been adapted to farming. Software development and information management systems have improved the ability of the farmer to manage complex agricultural production systems, especially for record keeping and marketing of crops.

The increasing complexity in agricultural systems requires more attention to management and greater finesse in the decision making process. Increased globalization has expanded competition, requiring producers to improve their marketing skills to get the best prices for their products. While some production systems have become more vertically integrated[41], other producers have found ways to recapture income through diversification of farm enterprises in which the producer maintains control, or an economic interest in, value-added products beyond the farm gate[14]. Additionally, increased social and political pressures to minimize environmental impact have increased record keeping requirements and confounded production choices.

Information systems can help manage much larger amounts of information and encompass a variety of technologies. Some information technologies include automated detection systems, such as remote sensing, soil sampling systems, and yield monitors, that allow producers to gather physical information about their production system. These rely on global positioning systems to spatially record physical attributes. Other information systems are designed as management tools for record-keeping, and may incorporate a geographic information system for spatially recording physical and economic information about the system and help make management decisions. More complex information systems, such as crop models, rely on data about the system and make management decisions based on predictive estimates of system function. These tools can be simple, requiring a minimal amount of data collection and computer technology, or complex, requiring extensive data collection and computer expertise. Sophisticated technologies that offer the potential to improve crop management such as precision agriculture[50] are often facilitated by information technologies. As the technology has advanced, potential cost benefits from implementing precision agriculture have improved[51].

The early stages of the development of information technologies fit a linear transfer of technology model, as technology was borrowed from other disciplines such as computer engineering and adapted to agriculture. Increased intensification of farms and improvements in computer and engineering technologies led to the development of

precision technologies for agriculture[50]. As the technology progresses, it is evolving into a learning selection model as more end-users are becoming involved in developing or modifying existing tools to suit their needs. However, the complexity of the systems and perceived limited or negative return on investment have hampered wide-spread adoption[52]. The learning curve for adopting information technologies can often be prohibitively steep, though as farmers' education levels increase, their use of computer technologies increases[52,53]. Simplicity of a technology and its potential to decrease risk have been identified as prime factors in the adoption of new technology[13]. The perceived absence of both of these factors is apparently limiting the rapid adoption of information systems in agricultural production. Adoption of technology is also age-related, as older farmers are less likely to adopt computers on-farm[53].

The most common information systems used by farmers are computers for financial and production record keeping and information gathering from the Internet[53]. More complicated technologies, such as crop models and decision support tools, have slower acceptance rates. As information technologies become more user-friendly and the user base becomes more knowledgeable about the potential utility of these technologies, development and adoption of information systems into agriculture are likely to increase.

In addition to their greater complexity, decision support tools rely on the knowledge of complex issues. Many of the factors impacting complex systems will not be observed through traditional reductionist research. Rather, the emergent properties of the system will only be observed in a systems research program. Future advances in the application of information technologies to agriculture may require a greater emphasis on systems research[54,55].

Information systems expand knowledge exchange through technologies such as the Internet and enhance the breadth of expertise available for identifying problems and developing solutions. Farmers now have access to more information more quickly and from a much broader range of sources than ever before. This allows them to make more rapid decisions, such as when to buy and sell products. Information technologies offer methods of integrating the disparate pieces of the production puzzle for information gathering and decision support. As the agricultural system becomes more complex, this information will be increasingly important in guiding farmers.

Implications for Future Agronomic Technologies

Social, political and economic pressures worked in concert to shape the evolution of the current agricultural production systems in the US[10]. Technological advances, often designed to address social concerns or overcome environmental limitations, further refined agriculture. While the current US agricultural systems are unquestionably highly productive, this abundance is based on an unsustainable use of natural resources and fossil fuels. Future challenges will exacerbate an already complex system and introduce new and greater problems[56]. Emerging technologies will be needed to address issues of economic and environmental sustainability, shifts in global population and consumption patterns and competition for land use.

Since technology is developed at the leading edge of our understanding, it is difficult to anticipate the impacts of that technology on the agricultural system. Since the 1930s, increases in production efficiency from technological innovations have occurred in conjunction with substantial structural changes in farming communities as fewer people are involved in agriculture[57]. In light of changing constraints to agricultural production, questions arise as to future advances in agricultural productivity, not from the standpoint of abundance, but of sustainability[4]. How, then, do we transition the current US production system to economically and environmentally sustainable production? While it may seem appealing, it is most likely neither possible nor desirable to discontinue technological advances.

A change in philosophical approach to address sustainability may be more important than simply changing practices[54]. Innovators in agriculture, including farmers, educators, researchers, businessmen, lawmakers, and so on, need to focus on more inherently multidisciplinary approaches to solve agricultural production problems. Moreover, there must be a broader focus on problem identification and resolution, incorporating societal, political and global goals of environment and nutrition together with producers' financial goals. In developing an economically and environmentally sustainable agricultural agenda, society must be willing to compromise its expectations, since current consumption levels of agricultural products, and the natural resources they require, are not sustainable[58]. New approaches to technology development and delivery have the potential to accommodate these needs by establishing a broad network of individuals with a diverse range of expertise, and working closely with the end users to identify goals, delineate problems and develop solutions[9].

Although the US has succeeded in developing an inexpensive, efficient food production and delivery system, over-consumption and lowered nutritional value have negative impacts on soil and water resources and human health[59]. Globalization makes a variety of foods available year round, but increases hidden costs due to transportation and compromises flavor and nutrition[60]. Food in the US is readily available and inexpensive in part because we have ignored the costs of natural resource depletion and non-renewable fossil fuel use in calculating the costs of production. While the caloric content of available food has increased worldwide, increased globalization and concentration of the food system has reduced local production of crops and limited distribution, access and

future food options[61]. Exploring the linkages between food, health, agriculture and the environment requires a different philosophical approach to agricultural production than a simple focus on yield[16], and is becoming an increasingly important component of the social environment influencing farming[5].

The current production system is not economically sustainable for farmers. Prices paid to US farmers have not kept pace with the cost of agricultural inputs (Fig. 1b)[2]. The unfavorable price shifts force increases in farm size, limit investment in agriculture and lead to political pressure for substantial farm programs to support agriculture and rural communities[5].

The world's growing population and increasing income imply increased demand for agricultural goods. Contrary to Malthusian expectations[62], however, to date supply has increased faster than demand. Currently, more than four people are fed per hectare of cultivated land, with just over 20 people being supported per irrigated hectare (Fig. 1c)[63]. Estimates of future population growth and rates of cultivated land use indicate a slow increase in population per unit of irrigated land[63,64], limiting the demand for agricultural products worldwide[65].

The integrated worldwide outcome of all factors affecting agriculture shows a rising historical trend in food production per capita (Fig. 1d)[2], which is projected to continue[63]. Rosegrant et al.[63]analyzed a number of future scenarios and found that, across a range of assumptions, agricultural supply is likely to keep pace with demand, resulting in similar or lower prices for agricultural goods out to the year 2020. While technology has helped realize this abundance, future advances will require a different mindset to better balance environmental and production goals and keep agricultural production economically viable.

Previous biological advances have come about largely from increases in the genetic potential of crops. Advances in biotechnology have expanded our ability to modify crop behavior beyond the range of conventional breeding techniques, improved quality and quantity of agricultural products, and incorporated unique value-added traits in newly-released cultivars. Future genetic advances will most likely come from value-added traits, such as neutraceutical and pharmaceuticals; addressing environmental constraints arising from agricultural intensification (soil erosion, water logging and salinity, coevolution of pests and pathogens, global climate change, loss of biological diversity, and limited water supply), and political, financial and human resource issues[4,66]. Additional benefits from advances in genetic technologies will allow improved identification and incorporation of superior traits and increased food safety through improved testing methods.

Improvements in mechanization have increased production output with fewer people, and improved the safety of farm workers. Future advances in mechanization will have to address power requirements of agriculture and the current reliance on fossil fuels. Additional engineering advances have the potential to conserve natural resources through more accurate application, and by better matching inputs with potential output. Improvements in harvest, processing and storing can retain nutritional value and enhance societal access to products.

Conservation systems address environmental, social and political concerns, and, where implemented, have made significant gains towards remediation of environmental damage. Conservation practices will continue to evolve and redefine environmental sustainability and impacts while maintaining production capacity. Future advances in environmental sustainability will come from greater implementation of conservation technologies, increasing the scope of conservation tools and practices to reduce reliance on non-renewable resources and chemical controls, and greater use and reuse of waste products from both agriculture and society.

Information technologies have the potential to address increasingly complex management issues by providing decision support tools for farmers. Additional information technologies will allow tracking products from start to finish and remote monitoring of crops and animals. The enhanced tracking of production will also allow better knowledge of chemical use and application, and prediction of potential environmental impacts. Marketing tools and internet access will assist producers in the global marketing of products.

On a larger scale, our definition of agriculture may change. Agriculture can be defined as the process of using natural resources (sunlight, air, water and soil) to produce a consumable product (e.g. food, fuel and fiber), while maintaining sufficient resources for the next generation. This definition could include alternative production systems such as wind turbine farms[67], which do not involve cultivation of the soil but do tie up a valuable natural resource (land) in the production of a consumable item (power). Similarly, ecosystem services, such as the buying and selling of carbon credits, are potential agricultural products[68]. As energy constraints and ecosystem services continue to escalate in importance, the management of the land for these purposes may surpass our current limited view of agricultural products.

Future production systems will need to be flexible to respond to rapid changes in climate and uncertainties in global markets from shifts in politics, production and population. In addition to addressing growing environmental concerns, sustainable farming systems will need to address energy concerns required for both agricultural production and as potential agricultural products.

An agricultural production system has been suggested that allows for dynamic responses to external pressures[57]. This dynamic management philosophy coupled with multiple cropping enterprises allows farmers to incorporate changes in their production system in response to changing needs. A dynamic system would be able to accommodate the increasingly complex factors influencing farmers today and reduce risks of production. Integrated farming systems

allow producers to optimize an array of factors, including environmental and financial, rather than simply focusing on yield alone. By carefully examining current production systems and the influences that have shaped them, we can develop future technologies that will address sustainability with the needs of farmers, society and the environment in mind.

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External economic drivers and US agricultural production systems

J.M. Halloran[1]* and D.W. Archer[2]

[1]US Department of Agriculture-Agricultural Research Service, New England Plant, Soil and Water Laboratory, Orono, ME 04469, USA.
[2]US Department of Agriculture, Agricultural Research Service, Northern Great Plains Research Laboratory, Mandan, ND 58554, USA.
*Corresponding author: John.Halloran@ars.usda.gov

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Abstract

US agriculture operates in a market driven economy, although government policies can have influence on what farmers produce and how they produce it. As with other businesses, agricultural producers respond to economic incentives and disincentives, and make decisions to maximize their welfare; usually measured as net income. We examined how external economic drivers shape the type of agricultural systems that producers adopt. Specifically, we considered the influence of technological advancements, income supports embodied in farm legislation, and changes in market structure and consumer demand. Changes in technology have often favored large-scale and specialized operations. Many of the technological advancements have required large-scale production units to justify the investment. Often the technology has been commodity specific. However, there is some evidence that more diversified production units might be able to achieve economies of both scale and scope. The influence of commodity support programs has been ambiguous. As farm legislation has evolved to decouple production decisions from program benefits, the incentives to specialize in program crops (crops that receive price and/or income benefits under federal legislation, such as corn, other grains and oil seeds) have diminished. However, wealth and risk effects, albeit small, may have promoted or inhibited the adoption of a more integrated system. The ability of producers to adopt more integrated systems has been primarily influenced by their natural resource base and proximity to markets. Changes in market structure, channels and consumer demand in the past five decades have been dramatic with consolidation and specialization in both production and marketing sectors. However, the diversity of consumer demand has also created opportunities for more integrated farm operations. There is an increasing number of consumers who have become concerned about how and where their food has been produced. Markets for organic, locally produced, free range and the like are expected to grow. While price and income supports may have been biased towards specialization (as these programs were targeted to specific commodities), the reduction in risk associated with the programs has enabled producers to expand the number and diversity of their production enterprises. Furthermore, through the use of strategic alliances, cooperation among producers on a regional basis may eventually lead to greater integration and diversification than could be achieved for the individual farm operation.

Key words: specialization, industrialization, economic incentives, Farm Bill, price and income supports, integrated systems, diversification, market structure and concentration, contracts, demand, strategic alliances

External Economic Drivers and Integrated Agricultural Systems

As stated, in the lead article of this issue, integrated agricultural systems are more sustainable and that sustainability must include long-term economic viability. Thus, we seek to identify factors that create incentives or disincentives for integrated agricultural systems. Not everyone agrees with the premise that one of the criteria for sustainability should include economic viability. For example, some suggest that sustainable systems should be based on ecological principles and the social and economic systems be modified to support these systems[1]. Another view posits that sustainable systems must enhance productivity to meet the growing demand of increased

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population growth[2]. Some argue that the wrong economic criteria are being employed, skewing the discussion in favor of large industrialized operations. They maintain that profitability may be a poor indicator of sustainability and that input balance, total energy use, and local employment associated with agriculture would be better measures[3].

The purpose of this paper is not to judge these arguments, but to evaluate how economic factors have influenced the shape of US agriculture with respect to farming practices, structural issues and the type of production systems found. We assume that agricultural producers respond to economic incentives, both monetary and non-monetary, and if producers are to adopt integrated agricultural systems, decisions will be largely based on economic incentives. Studies on technology adoption have shown that the potential profitability, compatibility and complexity, and the steepness of the learning curve have been key factors influencing adoption[4,5]. Although the use of diversified agricultural systems was already waning, the economic benefits of cropping diversity were enumerated in the early 1950s[6]. Expanding cropping diversity (or other enterprises) reduces income variability and risk as long as the enterprises are not highly and positively correlated in yields and prices. The principle is analogous to diversifying one's financial portfolio. However, the use of diversified agricultural systems was already waning as other factors created even larger economic incentives favoring specialization. In order to understand how current agricultural productions systems have developed and how they might change in the future, it is necessary to understand the economic factors shaping these systems. Our primary focus is on three external drivers; technology, farm policy and changing market conditions and structures.

Technological Drivers

In the early 20th century, farms employed close to half of the total work force. In 1930, agriculture accounted for about 8% of gross domestic product, today it stands at $<1\%$[7]. As the number of farmers has fallen by 63%, the average farm size has increased by 67%. This transformation has largely occurred as farmers have become more specialized. In 1900, an average farm produced about five different commodities. Today, the average farm produces one commodity. Specialization has been driven by technological advance[7]. Mechanization replaced draft animals and chemical inputs replaced those produced on the farm. Improved breeding and genetics increased the productivity of both plants and animals.

While some of these advances were size neutral, many of them, especially mechanization, favored larger operations. Tractors, harvest equipment and other equipment require a minimum usage (either acres or hours) in order to achieve optimum efficiency. Thus, as usage increases, producers' per unit costs decrease over a wide range of output. This phenomenon is commonly referred to as economies of size. Furthermore, much of the new technology has been geared toward production, harvesting and handling of specific crops. The adoption of new technology and the accompanying economies of size created incentives for larger farms and more specialized and less diversified farms. However, some studies have shown that larger operations, which achieve economies of size, are also able to achieve economies of scope[8]. That is, costs can be reduced when producing two or more products jointly, rather than strict specialization. It has also been observed that smaller farms tend to compensate for the lack of economies of size by seeking off-farm employment, and that greater off-farm employment has been associated with greater use of technologies that reduce on-farm management time, such as conservation tillage and use of herbicide-tolerant crops[9]. The literature has been unclear whether economies of scope can be achieved on smaller sized integrated operations.

US Farm Policy

Although other aspects of agricultural policy influence the design of agricultural production systems, price and income support programs have had the most direct impact on production systems due to the targeting of specific commodities. Modern US agricultural policy was initiated during the Great Depression of the 1930s to address low market prices and low farmer income. The initial act entitled the Agricultural Adjustment Act was adopted in 1933. The major tools were price and income supports and supply controls. In general, program benefits were linked to a farmer's historical acreage of supported commodities and historical yields[10]. The initial program covered wheat, cotton, corn, hogs, rice, tobacco and milk[11]. The program was subsequently expanded to include rye, flax, barley, grain sorghum, peanut, cattle, sugarcane, and sugar beet in 1934 and potato was added in 1935. However, with successive Farm Bills the list of eligible commodities increased and now includes oil-seeds and peanut, which formerly operated under a quota-based system.

The linkage of benefits to production created powerful incentives for farmers to produce crops covered under the farm program. Since the number of commodities has been limited, producers naturally followed the incentives to continued production of program crops. In addition to the direct income effects of price supports, there were also risk reduction effects[12]. These combined effects, as well as planting rigidities forced by supply control and an inclination for producers to protect their acreage bases, tended to increase technology driven specialization. Just and Schmitz[13] in their investigation of cropping diversity noted that relatively few economists had examined the potential impact of farm policy on cropping diversity versus specialization. Their findings were ambiguous. In many cases reducing support prices or acreage diversion increased specialization, perhaps reflecting attempts by producers to concentrate their efforts on their most profitable enterprise. A shortcoming of their analysis was that only major crops covering a relatively broad

geographic area were analyzed, so diversification occurring at the local level or other enterprises would have been missed in the analysis. By including livestock and off-farm investments in their analysis, Mafoua-Koukenbene et al. 1996[14] found reducing acreage diversion led to more diversification and higher off-farm investments. In a more recent study, researchers examining crop diversity along the US–Canadian border found that cropping diversity in the US region increased when acreage 'set asides' for wheat were imposed[15]. In 1996, the decoupling of subsidies from base acres resulted in a numerical shift to oilseed acreage, but it was not statistically significant. The lack of increased cropping diversity may have again reflected the regional aspect of their work. Perhaps the impacts could have been larger in the Corn Belt region where there is higher potential for increased diversity due to the natural resource base, better growing conditions and proximity to large population centers.

Across the numerous Farm Bills, price and income supports have evolved from commodity-specific prices to flexible supports including target prices and deficiency payments, loan rates and commodity loan programs. Prior to 1996, program benefits were tied to actual production decisions, i.e. the producer had to grow the commodity in order to receive a benefit. Thus, production decisions were biased toward program crops. Besides federal expenditure exposure, a major concern was that these programs interfered with market signals and often resulted in the government holding excess supply when crops used for marketing loan collateral were turned over to the government. The 1996 Farm Bill undertook a dramatic change by incorporating a system of direct payments and much greater planting flexibility to replace price supports and supply control programs. Farmers received direct payments based on their historic production (acreage and yields) rather than their current production[10]. Thus, farmers received direct payments whether they grew the crop or not. Growers were also allowed to grow any crop they wished, with restrictions placed on the production of fruits and vegetables. Fruits and vegetables were not allowed to be planted on historical program crop acreage without a reduction in their base acreage, so production of these crops could result in permanent reduction in the base acreage used for determining program payments. This bill 'decoupled' the program support from the actual production decision in an effort to allow farmers to respond to market signals instead of program benefits.

The 2002 Farm Bill introduced counter-cyclical payments that were triggered when prices dropped below a prespecified target price. This mechanism was introduced to avoid emergency support programs that were implemented several times under the previous act. The bill did allow producers to update their historical production bases and yields, and soybean was included for the first time. However, not all program benefits were decoupled from actual production choices. Both marketing loans and the crop insurance program, which subsidize premiums, were directly tied to production. These programs created explicit incentives to expand production of specific commodities[16].

The manner in which producers have responded to these government policies has been relatively unclear. The payment provisions of the past two Farm Bills influenced producer decisions in two basic ways. First, program benefits increased the wealth of producers. With increased wealth, producers may have increased the size of their operations and thereby decreased overall farm numbers. Although no strong evidence for the effect of government payments on farm size has been found[17], there is some evidence that government payments have had a greater positive effect on farm survival for larger farms than smaller farms[18], and that larger government payments may have been associated with greater rural population loss[19].

On the other hand, producers might use increased wealth to diversify their production systems[20]. However, as noted above, depending on which crops might be added, base acreage eligible for government support could be reduced. Most studies indicated that the wealth impact could lead to increased production of program crops; however, the overall impacts would be quite small[17,21]. The wealth effect could also impact the allocation of labor at the farm level. Although, there has been a trend toward greater reliance on off-farm income, government programs have been shown to have a negative effect on off-farm labor participation[12].

The Farm Bill could also affect producer decisions by altering a producer's preference for risk. Producers can be risk-averse, risk-neutral or risk-preferring[22]. Most farmers are thought to be risk-averse and they become less risk-averse as they become wealthier[19]. Therefore, consistent with observations of US farms, an increase in wealth caused by program payments could lead farmers to take more risk[21,23]. The potential impacts of taking greater risk on adoption of more integrated production systems versus expanding the current production system remain unclear[17]. While producers may be more willing to increase their risk exposure, the move to other commodities and, particularly non-program commodities, will have to be assessed with the introduction of a new enterprise. In that non-program crops would have no safety net, the income stream from these commodities could also be viewed as more variable than from a program commodity.

Producers who currently produce program crops may be hesitant to greatly reduce production of these crops. While present program benefits are not tied to actual production, they are tied to production history. In forecasting what changes might be embodied in future Farm Bills, producers might understandably assume future benefits will still be tied to historical production. Working on this assumption, producers would have an incentive to maintain current production patterns to maintain their acreage base[24,25]. Furthermore, as in the late 1990s, the emergency programs to stabilize farm incomes were tied to the production base. A risk-averse producer who assumes future program benefits will be similar to current ones would view the

decrease in historical production base as a distinct risk to future income streams. Thus, producers' expectations regarding future Farm Bills could reduce the likelihood of diversifying the commodity mix.

While the evidence is unclear regarding the overall impact of farm programs on diversification, there are opportunities for producers to take the certainty of program benefits as an incentive to produce other crops. In an USDA–Agricultural Research Service workshop held in Auburn, Alabama, one producer noted that he had greatly diversified his cropping mix and raised feeder cattle as well. His cotton base gave him the opportunity to diversify. Program benefits, such as direct payments, were known with a reasonable degree of certainty and allowed him security to diversify his production efforts. Similarly, some potato producers in Maine have established strategic alliances with dairy producers. As part of their rotation sequences, potato producers grow silage corn as feed for dairy cattle and they use the manure from a dairy producer's operation as fertilizer[26]. The direct payment for corn under the Farm Act greatly reduces the economic risk for the potato producer. The arrangement also enables the potato producer to employ a longer rotation sequence within the potato production system, thereby improving the productivity and profitability of the subsequent potato crop.

Overall, the decoupling of benefits in the Farm Bill from actual production decisions has expanded the opportunities for producers to become more diverse. Although there may be incentives for increased production of program crops, there are also increased incentives (or reduced disincentives) for diversification.

Markets for Agricultural Products

As in agricultural production, food marketing firms have adopted new technologies that created economies of size in processing and distribution. Adoption of new technology by food marketers has also influenced the type of agricultural production systems employed by producers. Other forces such as the increased demands for variety, convenience, packaging, quality, and recently, how agricultural commodities are produced, have also transformed the food marketing system[27]. Today's consumers are demanding a wider variety of goods, higher quality, information on how and where goods are produced, and have greater concerns for food safety. Marketing costs now represent the majority of the consumer's food dollar. The increase in the marketing bill has been accompanied by a similar decrease in the producer's share of food expenditures. The reduction in food costs (both at the farm and retail level) is driven by technological advancements throughout the food marketing system.

With growing demand for convenience, eating habits of many consumers have also changed, reflected in people eating more meals away from home. According to USDA analysis, over 40% of the consumers' food dollar is now spent on meals away from home[27]. This trend has led to the development of major restaurant chains. Importantly, these chains became national in scope. They represent a significant market for US agricultural production, and have significant influence on how the goods they purchase are produced. The emergence of major restaurant chains is consistent with overall increasing consolidation of food marketing firms. Consolidation was driven by the goal of increased efficiency. Supply chain management became a driving force in the food system. The development of mass merchandisers increased the competitive pressure on traditional supermarkets that were already experiencing low sales growth in response to increased food consumption away from home[27]. One method traditional supermarkets have attempted to maintain or increase their profitability has been by reducing the costs associated with acquiring their merchandise. As food marketing firms have emphasized increased productivity through supply chain management, some of the tasks traditionally carried out by these firms have been transferred to their buyers.

The drive towards increased efficiency has led to a reduction in the number of firms and an increase in their size at all stages in the food marketing system. Food marketers beyond the farm have had a greater emphasis on supply chain management. One method to increase efficiency has been to reduce the number of suppliers. Preferred suppliers have large volumes and they carry a broad array of products. Furthermore, retailers have shifted many tasks to their suppliers. Some of these tasks include inventory management, promotional support and stocking. As of 2003, supermarket chains were relying on only three to four providers for the bulk of their produce supplies[28].

The push for efficiencies through supply chain management and the need for greater specificity in product attributes, due to food marketers catering to a wider range of consumer preferences, has led to increasing amounts of agricultural products being grown under contract production. In fact, 39% of the value of US agricultural production was governed by marketing and production contracts in 2006[29]. This was up from 11% in 1969. There are several types of contract production, but the two most prevalent types are marketing and production contracts. Marketing contracts generally specify quantities, quality levels, storage requirements and delivery schedules. The contract also contains a formula for final price determination. The formula usually contains incentives (disincentives) for superior (inferior) performance or quality. These contracts are normally negotiated every season. Marketing contracts are the most common type of contract for crops[30].

Production contracts have many of the attributes of marketing contracts. However, production contracts make production practices explicit, and the contractor often owns the commodity while it is being produced. In many cases, the buyer will provide many, if not most, of the production inputs. Production contracts are common in poultry and hog operations. Production contracts may be multi-year in length, although, they can be as short as a single growing season (<1 year) or a single flock (<2 months)[26]. More

than half of the broiler contracts were <1 year in 2003 and another 22% of the producers contracted for a single flock. However, 37% of market hog contracts were for periods of >5 years[27].

Marketing and production contracts assure market access and reduce price risks for the contracting producers. They also assure supply for the contractor, enabling buyers to more efficiently schedule the use of their facilities, help facilitate traceability and ensure specific production practices. Contracting does raise some concerns. As more commodities are produced under contract, open market transactions may less accurately reflect supply and demand conditions, become more costly, and may be more prone to market manipulation[31–33]. However, evidence of market manipulation is not conclusive[34] and recent attention has focused on potential differences in the impacts of specific contract provisions[35,36]. While contracting can reduce certain risks, there is also a possibility that contractors can transfer some of their risk to the producer.

Although the literature has been unclear regarding the impact of contracting on integrated systems, most producers who contracted have been from large commercial farms[35]. This is consistent with the idea that, due to the transactions costs associated with contracting, contractors have an economic incentive to deal with fewer, larger farms. There is evidence that large farms which rely heavily on contracts have had a significant competitive advantage over small farms[8], however, there is also evidence that diversification plays an important role in this competitive advantage[37]. Although this appears contradictory to overall trends toward specialization and evidence that contracts lead to a greater degree of specialization[38], the principle has been supported by earlier observations of a positive relationship between farm size and diversification[23]. Contracting requires assets that are specific to the commodity produced on both sides of the transaction (producers and contractors). As a result, contract production has not fostered the growth of integrated agricultural systems. The economic incentives toward large-scale agribusinesses contracting with a smaller number of large farms may, however, provide incentives towards regional-scale integrated systems similar to the alliance between Maine potato producers and dairy producers noted earlier[39].

As mentioned, consumers have become increasingly concerned about how their food is produced. For example, over the past several years the demand for organic food has increased at an annual rate of 20%[40]. Furthermore, organic price premiums over conventionally produced food have been maintained[40], indicating that demand has been increasing at a faster rate than supply. This pattern is not just limited to organic production. Other food labels, such as sustainable, locally produced, grass fed and free range, have also been used to stimulate sales. Large food marketers are responding to these demands as a method to stimulate or maintain sales. The three largest fast food chains now require more humane production conditions for the animals used in their products[27]. The key to successful marketing under the various 'green' labels appears to be third party certification. Under the current Organic Foods Act, third party certification is required before the producer/manufacturer can use the USDA Organic label. Although, most trends in the food marketing system appear to be neutral or biased against integrated agricultural systems, the 'green' phenomenon could foster such systems. Third party certification is seen by some as a way to create more sustainable production and consumption systems and to incorporate ethical practices into existing systems. However, third party certification may in some cases be a requirement for market access rather than a means of obtaining price premiums, and the costs involved with obtaining third party certification can represent an economic barrier for small producers[41].

Many of the production principles used in organic or sustainable production are consistent with integrated agricultural systems. However, some organic vegetable and milk production systems have demonstrated that the industrial model already has significant influence on organic production[42]. While the presence of organic standards has helped boost markets for organic products, there are concerns that national standards may undermine the environmental and social sustainability goals of organic agriculture[43].

Several of the identified market trends, such as supply chain management and contracting, favor larger-scale and more specialized production systems. However, some emerging and established institutional arrangements could contribute to the increased adoption of integrated agricultural systems. In recent years, both formal and informal strategic alliances (arrangements that benefit both parties) have grown in use. One example involves a Maine potato producer, who produces broccoli in his rotation sequence. He has determined that in order to be competitive, a steady volume is required throughout the year. Therefore, he established strategic alliances with producers in the mid-Atlantic region and Florida. Marketing under a common label, these producers can achieve the continual presence in the market. Furthermore, this arrangement has enabled the Maine producer to grow broccoli on his neighbors' fields thus providing the neighboring potato producers with an additional, high value rotation crop. Similarly, other farmers have expressed renewed interest in cooperative marketing.

Summary and Outlook

In our discussion of economic drivers, we have concentrated on technology adoption, government programs and changes in the market place. These drivers share common elements. While some technology has been size neutral, much has not. In general, much of the technology adopted throughout the food chain has created incentives for producers or firms to expand their production to capture economies of size. In general, this effort has also included increased specialization. Previous government policy reinforced the trends of increased size and specialization

by supporting production of specific commodities. Food marketing firms have faced some of the same incentives (especially the reduction of per unit costs), and thus have preferred to work with suppliers with considerable volume. These forces appear to be obstacles to developing integrated agricultural systems. However, examples from innovative producers can provide some insight regarding how these drivers may be used to foster integrated agricultural systems. An integrated producer in Alabama used the cotton program as a method to reduce overall economic risk, enabling him to develop a broad and diverse system of livestock and other crops. This suggests a need to identify potential rotation crops and livestock operations that are compatible within a system that includes program crops. While whole-farm profitability is important, the impact on economic risk of a truly integrated agricultural system versus a traditional program crop rotation system may be as important. A second need involves redefining the production unit, i.e. the integrated agricultural system. In some cases, the relevant area of interest may be the landscape or the community[39]. The concept of integrated dynamic systems can also be applied across ownership. The case of Maine potato producers and dairy producers cooperating to maximize the use of their land base and manure has already been mentioned regarding the benefits of federal programs[26]. In addition, the relationship enabled potato producers to grow more acres of potato and use silage corn as a rotation crop. The study found that potato and dairy systems coupled for 2 years had greater indications of profitability and sustainability than did their conventional non-coupled systems. A key to their success was the close proximity of the cooperators. The Maine potato–broccoli producer's strategic alliance noted earlier was predicated on increasing the land base, since there was a need for a 4-year rotation. The producer now 'swaps' fields with neighboring potato producers, who receive a larger return than they would from the standard barley rotation crop in the Maine potato production system. As demonstrated by these producers, researchers may be unnecessarily restricting themselves to individual farm units. Through cooperation, individual producers may be able to reap the benefits of integrated agricultural systems, although they may still maintain their identity as a potato producer or dairy farmer. The necessary conditions fostering this cooperation and the barriers that prevent cooperation must be examined.

Market trends seem to favor large-scale and specialized operations, but recent developments may foster integrated agricultural systems. A significant number of consumers are becoming concerned about how and where their food is produced. Although organically produced food currently has the greatest cachet, some predict that locally and sustainably grown products may become as desirable. Reflecting this interest, the term 'food mile' (how far the product moves from the field to the plate) has been coined. Some of this was driven by reducing fuel use and reducing the carbon footprint.

A growing number of food marketing firms are embracing corporate social responsibility policies. These policies broaden the firm's objectives beyond financial performance to include others, such as sustainable growth, equity considerations, social and environmental well-being. For example, many of these policies are focused on where and how the raw ingredients of their products are produced. These firms are responding to the concerns of their customers. This combination of consumer concern and corporate social responsibility could expand the demand for food products that are produced in a more sustainable fashion, including reduced environmental impacts.

However, other real economic benefits may result in the revitalization of rural economies and communities, leading to increased incomes and a reduction in social problems. Research in this area has been limited. Besides production research, the development of human capital and the supporting infrastructure will be equally as important to facilitate the connection between producers and their customers. Without local outlets transportation costs may keep a producer out of the market, especially for the small and medium-sized producer. Pennsylvania has addressed this issue by establishing wholesale production auctions to serve local communities[44]. In 2001, the average sales per auction was US$3.5 million.

In the beginning of our discussion, we identified economic incentives as determining the type of production systems used. A recent review of dynamic cropping systems found them to be more robust than traditional, more specialized systems[45]. Due to complementarities among the crops grown, integrated systems are better able to withstand disease and nutrient and water stresses than conventional systems. These attributes should contribute to increased profitability. Furthermore, the diversity also reduces income variability and the risk of financial catastrophe. These are real economic incentives and, combined with the changes in consumer demand, may provide the opportunity for greater adoption of integrated systems. All the economic benefits and costs (market, environmental, social and community) associated with integrated production systems need to be identified in order to foster adoption.

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Environment and integrated agricultural systems

J.R. Hendrickson[1,*], M.A. Liebig[1], and G.F. Sassenrath[2]

[1]USDA-ARS, Northern Great Plains Research Laboratory, PO Box 459, Mandan, ND 58554-0459, USA.
[2]USDA-ARS, Application and Production Technology Research Unit, PO Box 36, Stoneville, MS 38776, USA.
*Corresponding author: john.hendrickson@ars.usda.gov

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Abstract

Modern agriculture has done an excellent job producing food, feed and fiber for the world's growing population, but there are concerns regarding its continued ability to do so, especially with the world's limited resources. To adapt to these challenges, future agricultural systems will need to be diverse, complex and integrated. Integrated agricultural systems have many of these properties, but how they are shaped by the environment and how they shape the environment is still unclear. In this paper, we used commonly available county-level data and literature review to answer two basic questions. First, are there environmental limitations to the adoption of integrated agricultural systems? Second, do integrated agricultural systems have a lower environmental impact than more specialized systems? We focused on the Great Plains to answer these questions. Because of a lack of farm-level data, we used county-level surrogate indicators. The indicators selected were percent land base in pasture and crop diversity along a precipitation gradient in North Dakota, South Dakota, Nebraska and Kansas. Evaluated over the four-state region, neither indicator had a strong relationship with precipitation. In the Dakotas, both percent pasture land and crop diversity suggested greater potential for agricultural integration at the mid-point of the precipitation gradient, but there was no clear trend for Kansas and Nebraska. Integrated agricultural systems have potential to reduce the impact of agriculture on the environment despite concerns with nutrient management. Despite advantages, current adoption of integrated agricultural systems appears to be limited. Future integrated agricultural systems need to work with environmental limitations rather than overcoming them and be capable of enhancing environmental quality.

Key words: Shannon's diversity index, environmental limitations, sustainability, climatic change

Introduction

Human population growth in the 21st century will increase demand for food, feed and fiber well above current production levels[1,2]. Agriculture will need to become more resource intensive in a world where nonrenewable resources are increasingly scarce and have significant environmental drawbacks[3]. Furthermore, these challenges will be addressed when global climate change is accelerating[4], the impacts of which are projected to have overwhelmingly negative effects on agricultural production systems[5–7].

To understand how environmental issues will impact agriculture systems in the future, it is necessary to evaluate how the environment is currently impacting agricultural systems. Linkages between the environment and agriculture are most clearly characterized by the delineation of agro-ecoregions[8], where prevalent agricultural practices are defined by climatic and soil attributes within a specified area. The importance of this linkage can be seen in the common use of terms such as 'Corn Belt' to define agriculture in the central US, or 'Cotton Belt' in the southern US. Within a geographic region, the environment has a strong role in determining the long-term success of a particular cropping system[8] or the productivity and relative abundance of native grass species[9].

Agriculture has used an industrialized production model, where crops and animals are produced in systems that are increasingly specialized, simplified and concentrated, to address growing food, feed and fiber demands[10]. Within this model, external inputs (e.g. irrigation, synthetic fertilizers,

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chemical pest control) have been utilized to achieve production goals, often at the expense of environmental quality and key ecosystem services[11]. Based on past performance, continuation of this model of agricultural production may result in loss of ecosystem services, increased ecosystem simplification and species extinction[12].

Responses to future challenges in agriculture should include the development of novel systems that are highly productive, minimize damage to the environment, and effectively utilize renewable resources[13]. Achieving these multiple goals will be a momentous task, as it will require development and implementation of more complex, diverse and management-intensive production systems than currently employed[10]. Furthermore, future agricultural production systems will need to be adaptable to respond to unforeseen environmental challenges[14]. Integrated agricultural systems have been purported to possess these attributes. Integrated agricultural systems have been defined as agricultural systems with multiple enterprises that interact in space and/or time in a manner such that the interactions result in a synergistic resource transfer among enterprises[14].

For integrated agricultural systems to be a viable future option, two basic questions need to be raised to better understand their responses to, and affects on, the environment: (1) Does the environment impact the adoption of integrated systems? and (2) Do integrated agricultural systems have a lower impact on the environment?

We attempted to answer these questions, realizing the questions are broad in scope and answers may not be forthcoming due to lack of data. For example, acquiring data on integration at a farm-level in the US is difficult. Furthermore, comprehensive assessments of environmental benefits from integrated agricultural systems are lacking because of the limited number of long-term evaluations[15]. Because of these restrictions, much of our analysis was done using surrogate variables and focused on specific strategies for achieving environmental sustainability.

We limited the scope of our evaluation to the Great Plains region of the US. We chose this region for several reasons. While unique, the Great Plains can be considered a transitional region from the humid (and farming dominated) east to the arid (and ranching dominated) west. The Great Plains is characterized by a relatively consistent landform and soil type with differences in production driven primarily by climate. Climate on the Great Plains is highly variable with extremes in both temperature and precipitation. Weather variations can test the sustainability of agricultural systems.

Environmental Impacts on Adoption of Integrated Agricultural Systems

An FAO[16] report suggested that cheap resources lead to specialization and restricted resources lead to integration. Although this report had a global focus, we were interested in determining if the concept could be applied to US agriculture. Specifically, we sought to determine if environmental resource availability could impact the degree of integration in US production systems. In order to test this idea, we focused specifically on precipitation.

Water is a critically important resource for agricultural production. Vegetation uses and transpires large amounts of water[17] which is supplied through precipitation or irrigation. Regional suitability of crops is often determined by crop water requirements[18]. Occasionally, lack of precipitation is overcome through irrigation, often at a significant cost to the producer[19]. Therefore, precipitation meets the requirements of a restricted resource, especially in arid and semi-arid areas. If, as suggested, restricted resources lead to greater amounts of integration, then drier areas should have more agricultural diversity than wetter areas. Agricultural diversity should lead to more enterprises, thus forming the basis for integrated agriculture systems.

The central and northern Great Plains is an ideal region to evaluate a potential association between precipitation and integration of agricultural enterprises. The Great Plains are characterized by decreasing precipitation from east to west and decreasing temperature from south to north[20]. The primary landscape feature of the Great Plains is gently rolling plains[8] and the soils are primarily mollisols[21]. Therefore, east to west transects within a state should vary primarily in precipitation, with growing season, soil type and landform being relatively constant.

Because of limited data, estimating farm-level integration is difficult. However, the use of surrogates can provide insight into agricultural integration at a broader level. County-level data exist for land area in cropland and pasture[22]. Data also exist for major crop types grown in each county[23]. These data provide some broad parameters for evaluating level of integration. For example, pasture lands are primarily grazed by livestock; therefore, existence of cropland and pasture land in a county can indicate the potential for farms to have mixed crop and livestock components or the possibility of mixing crops and livestock between farms[16]. Accordingly, a relatively diverse mix of crops within a county suggests producers rely on more than one or two crops in their cropping systems.

A precipitation gradient was developed by establishing east–west transects in North Dakota, South Dakota, Nebraska and Kansas. Along each transect, every other county was selected for evaluation, beginning at the very eastern edge of each state (Fig. 1). Transects were located to avoid large areas with atypical soils such as the Nebraska Sandhills and the Kansas Flinthills. Variables evaluated were pasture as a percent of total land base and crop diversity. Crop diversity was evaluated using the Shannon diversity index[24], where H' is an estimate of diversity and is calculated as:

$$H' = -\sum_{i=1}^{n} p_i(\log p_i), \quad (1)$$

where p_i is the proportion of the ith species relative to the total number of species. Shannon's index allows for a

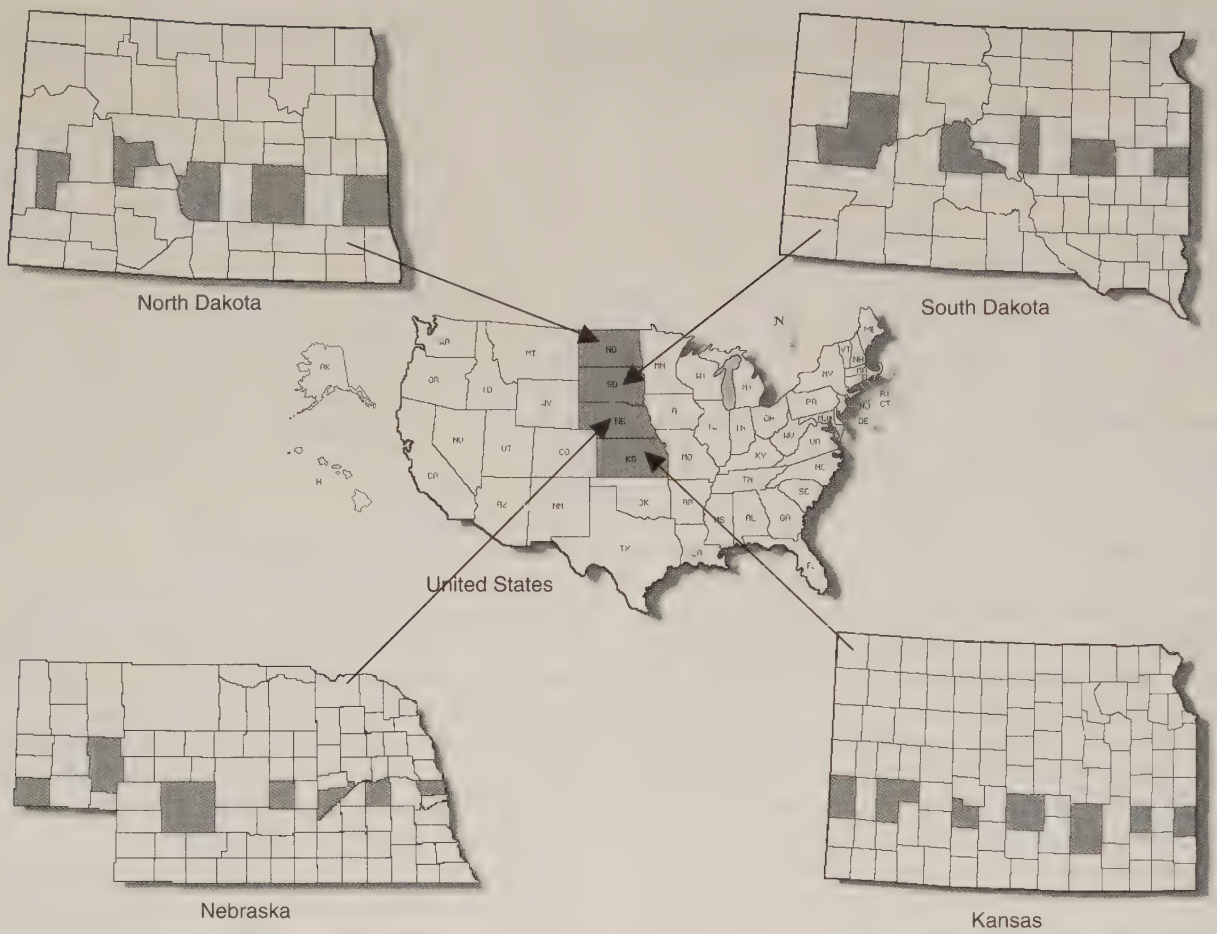

Figure 1. Transects were conducted in the states highlighted in gray. Counties within each state that were used in the east to west transects are highlighted in gray in the insets. Locations of transects were selected to avoid atypical areas to the greatest degree possible.

calculation of not only diversity, but also evenness, which is defined as the relative abundance of each species, or in this case, crop type.

Mixed crop and livestock systems are the best known examples of integrated agricultural production systems[16]. While integrated crop–livestock systems can be developed in all cropland or all pasture land, in the Great Plains, the greatest potential for integrated crop–livestock systems exists in areas of mixed crop and pasture land. This means that percent of land in pasture is an important determinant of integration potential. In the four-state region (Kansas, Nebraska, South Dakota and North Dakota), percent of land in pasture was the highest at the two extremes of the precipitation continuum (Fig. 2A). This was surprising, because generally the amount of land in pasture would be expected to increase as precipitation decreases. This was true of South Dakota and North Dakota (Fig. 2C) but not of Kansas and Nebraska (Fig. 2B). However, this response was primarily driven by an increase in percent land in pasture in eastern Kansas (Fig. 2D). In the other three states, percent land in pasture decreased as precipitation increased (Figs. 2E–G). Although the amount of land in pasture is a surrogate for actual agricultural integration, the increased pasture land in the drier areas suggests there is greater integration potential in the areas of resource scarcity.

Irrigation may have affected the percent of pasture land in drier areas of Nebraska and Kansas. Kansas and Nebraska have over 3.5 and 7.5 times the irrigated acreage as the Dakotas, respectively[25], and the Ogallala Aquifer, a major source of irrigation groundwater, lies under the western parts of both the states[26]. Irrigated cropland, as a percent of total cropland, increased with decreasing precipitation in Kansas, but in Nebraska percent irrigated cropland peaked in the area with more precipitation[25]. In both the states, the driest county in the survey had relatively little irrigation[25]. Other factors such as land productivity and relative economic benefits also determine land use[27].

More crops indicate more potential enterprises, which can lead to synergisms in resource flow[14]. Therefore, crop diversity may also serve as a surrogate indicator of integration within agricultural production systems. By combining county-level data for crop type[23] with long-term precipitation[28], we plotted Shannon diversity index estimates for states in the central and northern Great Plains (Fig. 3). When the data from all four states (Fig. 3A) or

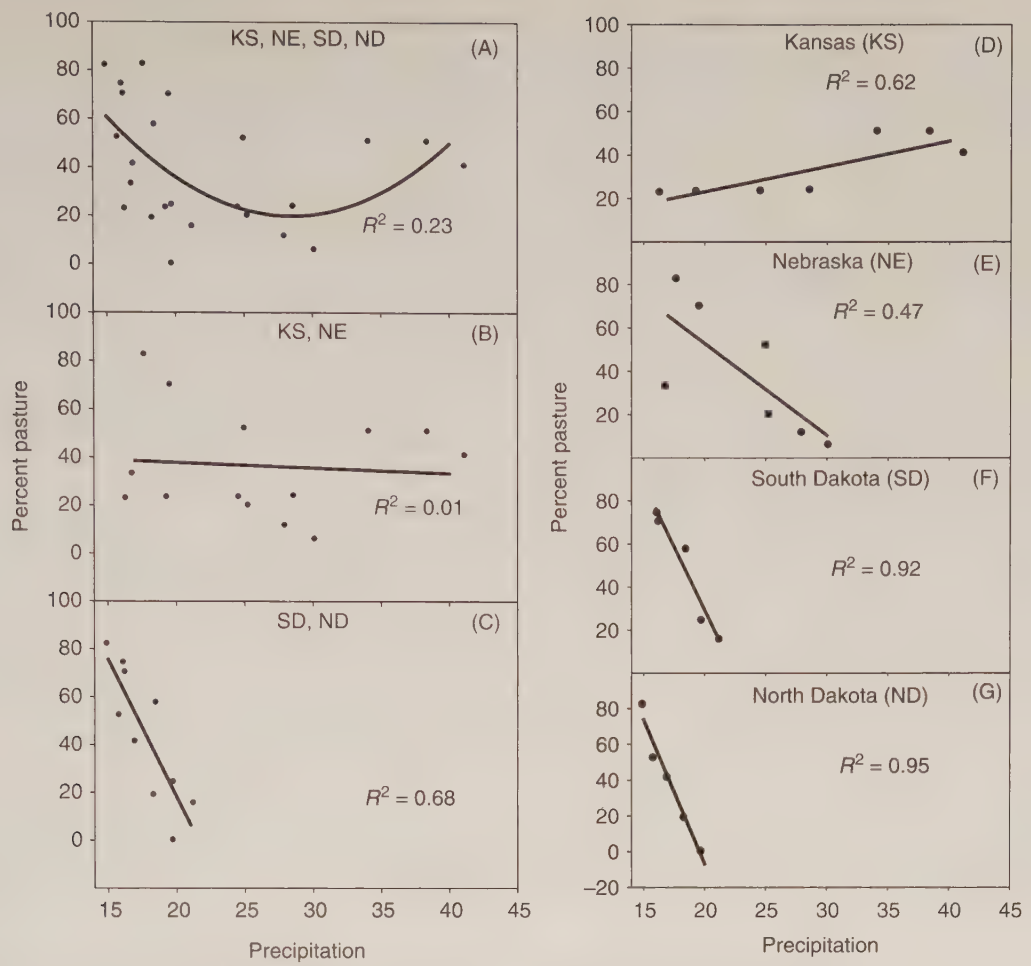

Figure 2. Percent of land in pasture for selected counties on a west–east precipitation gradient (A) pooled over Kansas (KS), Nebraska (NE), South Dakota (SD) and North Dakota (ND), (B) pooled over KS and NE, (C) pooled over SD and ND, (D) KS only, (E) NE only, (F) SD only and (G) ND only in the Northern Great Plains. Information was adapted from the 2002 Census of Agriculture[22].

from just Kansas and Nebraska (Fig. 3B) were combined, there was no strong relationship between precipitation and Shannon Diversity Index. This was driven by the strong linear relationship between precipitation and crop diversity in Nebraska compared to a quadratic equation in Kansas (Figs. 3D and E).

The combined data for North and South Dakota (Fig. 3C) and individual state data for North Dakota, South Dakota and Kansas (Figs. 3D, F and G) had a quadratic response between precipitation and diversity. Lower crop diversity in the wetter and drier ends of the precipitation gradient may be caused by two factors. First, producers may have selected crops that are relatively risk-free in those areas. For example, dryland corn requires at least 25 inches of annual precipitation[29], so producers may limit the amount of dryland corn they plant in semi-arid areas because of the risk of crop failure. However, in the middle of the precipitation gradient, greater crop diversity may give producers the opportunity to enhance revenue in good years but still manage risk with safe crops in bad years. Finally, in the more arid areas wheat may be the safest crop to plant because of limits in precipitation. In the Dakotas, the shorter growing season may also impact crop diversity.

The theory of extensive margins[27,30] may be the second factor driving crop diversity in response to precipitation. In this theory, areas on the economic margin between two or more competing economic uses will see the greatest change in land use for a relatively small change in price[27]. For example, in the wetter areas corn and soybean are high-value crops. Because they are well suited to higher precipitation, it would take a dramatic price shift to change to an alternative crop. However with intermediate precipitation, corn and soybean production is riskier and other crops become more competitive. In these regions, small price changes can result in large changes in planted acreages. Finally, with the lowest precipitation, wheat becomes the highest value crop because of greater assurance of production.

It is difficult to explain the linear response of crop diversity to precipitation in Nebraska. The production of dry edible beans, including pinto beans, and sunflower increased the crop diversity in western Nebraska leading to a greater Shannon diversity index. Correlations between the percent of total cropland that was irrigated and the Shannon diversity index were non-significant for both Nebraska and Kansas. Producer familiarity with alternate crops or local

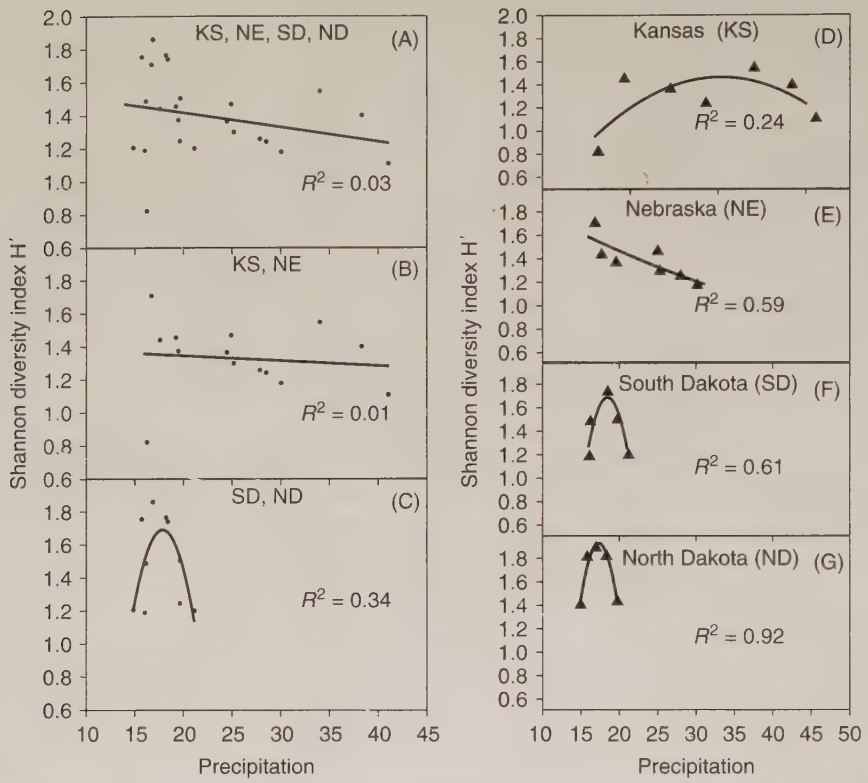

Figure 3. Crop diversity calculated using a Shannon diversity index (H′) for selected counties along an west–east precipitation gradient (A) pooled over Kansas (KS), Nebraska (NE), South Dakota (SD) and North Dakota (ND), (B) pooled over KS and NE, (C) pooled over SD and ND, (D) KS only, (E) NE only, (F) SD only and (G) ND only in the Northern Great Plains. Data were complied from USDA–NASS state statistical offices.

market conditions may have contributed to the increased diversity in western Nebraska.

If all external drivers were equal, adoption of integrated agricultural systems would be one way to evaluate their viability in the variable weather patterns of the Great Plains. Swenson[31–35] conducted an inventory of mixed farms in North Dakota, where a 'mixed farm' was defined as a farm that received <70% of its revenue from either crops or livestock (Fig. 4). Because participation in these surveys was voluntary, these farms were not statistically representative, and therefore, data would not necessarily match statewide adoption trends. Despite these limitations, the data provided some insight into adoption of mixed, but not necessarily integrated, agricultural systems. The percent of surveyed farms that were mixed dropped dramatically in the early 1990s and then increased and stabilized at about 16% (Fig. 4). Regions of North Dakota with the most mixed farms were the south central and western parts of the state[31,35].

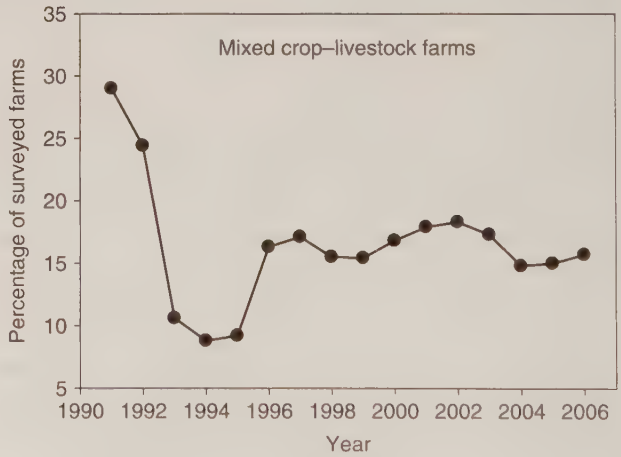

Figure 4. Percent of surveyed North Dakota farms considered to be mixed farming enterprises. These farms had <70% of total sales from either crops or livestock. Data were collected from the Financial Characteristics of North Dakota Farms series[31–35].

Because of the lack of individual farm data, surrogate indicators were used to determine if environmental factors impacted the adoption of integrated agricultural systems. While the data revealed some trends within a state or even combining several states, these trends did not hold up when the data for all the four states were combined. Within the Dakotas, the amount of crop diversity and the even split between cropland and pastureland at the intermediate precipitation amount, suggest that these areas have the greatest potential for integration. In Kansas, the greatest potential for agricultural integration, based on crop diversity and land in pasture, would be in the eastern part of the state while in Nebraska; these same indicators would

suggest greater integration potential in the west. While the most plausible explanation for the differences between the Dakotas and Nebraska and Kansas would be the availability of irrigation, the data do not provide strong support for this explanation. Other factors such as landform and length of growing season may also impact integration potential. While the use of the surrogate indicators provided interesting information, it is apparent that evaluating the impact of environmental factors on adoption of integrated agricultural systems requires farm-level data.

Environmental Impacts of Integrated Crop–Livestock Systems in the Great Plains

Agricultural producers tend to use highly productive land for crop production[27]. However, marginal lands, which are less productive and more prone to environmental damage, are periodically put into and taken out of crop production[27]. The northern Great Plains, in particular, is one of the leading regions of the US in terms of changes in cultivated land[27]. This practice combined with the variable weather conditions in the Great Plains[20] and an overall increased social sensitivity to environmental issues[36] requires an understanding of the environmental impacts of agricultural production systems in the northern Great Plains.

Documenting environmental impacts of agricultural production systems is an essential component of sustainability assessments. Assessments linking management strategies with sustainability goals are particularly useful, as they provide a clear direction for producers to implement new—or improve current—production practices to achieve greater sustainability[37]. In this regard, Doran[38] developed a framework for assessing environmental sustainability of agricultural production systems using soil quality as a linkage between management strategies and goals of sustainable agriculture. Strategies proposed by Doran[38] included conservation of soil organic matter, minimizing soil erosion, balancing production and environmental outcomes, and improving utilization of renewable resources. The objective of these strategies was to provide sufficient food and fiber, while concurrently maintaining environmental stability, ecological integrity, and the quality of essential soil, water and air resources. For purposes of this paper, the four strategies developed by Doran[38] will be used as a guide to briefly review the environmental impacts of integrated crop–livestock systems, or more generally, of integrated agricultural systems.

Conservation of soil organic matter

Increases in soil organic matter are associated with improvements in soil physical properties and nutrient cycling potential, both of which contribute to higher crop yield potential[39,40]. Consequently, it is important to understand the effects of integrated agricultural systems on soil organic matter.

Livestock play a key role in the maintenance and accumulation of soil organic matter through manure addition. Whether applied directly via grazing livestock on cropland or through collection and distribution from concentrated livestock facilities, manure serves as an important carbon source for potential incorporation into soil organic matter. Outside the Great Plains, manure addition to cropland has been well documented to either maintain or increase soil organic matter (see reviews by Johnson et al.[41], Franzluebbers[42] and Liebig et al.[43]). Within the Great Plains, increases in soil organic matter have been observed with application of beef cattle manure or composted feedlot manure in corn- and sorghum-based cropping systems[44,45]. It is important to note, however, the effectiveness of manure in increasing soil organic matter is influenced by the quality of material, with manures mixed with bedding material being more effective than manure slurries[15].

Inclusion of perennial forages in integrated agricultural systems contributes significantly to increased soil organic matter. Relative to many annual crops, perennial forages have greater root biomass and deeper rooting depths, both of which contribute to organic matter accumulation over time[46,47]. Rates of soil organic matter accumulation are often greatest following establishment of the perennial phase in rotation[15], and can be increased through grazing[48]. Though data are limited, inclusion of a perennial cropping phase in Great Plains cropping systems has been found to increase soil organic matter[49,50].

Minimizing soil erosion

Perennial cropping phases are a central component to integrated crop–livestock systems, the inclusion of which can significantly reduce wind and water erosion from agricultural lands. Soil erosion from perennial grass pastures has been found to be nearly zero across a range of soil types and growing conditions[15,48,51]. In arid and semiarid regions, including a perennial cropping phase in annual cropping systems can also provide significant protection from wind erosion[15]. Furthermore, positive residual effects from including a perennial cropping phase on wind erosion mitigation have been observed over an entire rotation sequence[52]. Although documented effects of erosion mitigation are apparent in integrated crop–livestock systems, use of reduced or no-tillage management techniques during establishment of the perennial cropping phase is critically important to protect soil when it is most susceptible to erosion[48].

Balancing production and environmental outcomes

Balancing production and environmental outcomes within agroecosystems requires the application of management practices that effectively optimize variables of agronomic performance and environmental quality. Pragmatically, these management practices must be conservation-oriented, in that

there is a clear emphasis on maintaining or enhancing the natural resource base on which agricultural production depends[38]. Concurrent to an emphasis on conservation is the use of production strategies that take advantage of ecological synergies among production enterprises so that inputs (e.g. nutrients and water) are used as efficiently as possible[53].

Integrated crop–livestock systems have been documented to balance production and environmental outcomes more effectively than specialized agricultural production systems[15], though definitions of 'success' strongly depend on site- and resource-specific contexts within working farms. Notable management approaches with the greatest potential to achieve these outcomes include diversified cropping systems under no-till management[54] and inclusion of perennial cropping phases in crop production systems[55]. At least within the Great Plains, both of these management approaches are highly relevant and have proven to impart positive effects on system productivity while conserving natural resources[56]. Additionally, these management approaches can disrupt insect, weed and disease cycles[57,58], thereby reducing dependence on pesticides.

Improving utilization of renewable resources

Integrated agricultural systems have significant potential to improve utilization of renewable resources over more specialized forms of agricultural production. Expansion of crop portfolios to include legumes in integrated crop–livestock systems have been particularly effective at utilizing renewable resources, since these crops can fix atmospheric N, thereby decreasing requirements for fertilizer N[56]. Ranges of nitrogen contributions from 6 to 28 kg N ha^{-1} have been reported for annual legumes or pulse crops[59,60], and when used as green manure, these can contribute between 95 and 192 kg N ha^{-1} yr^{-1} to the soil depending on the environment in which they are grown[61]. Perennial legumes, such as alfalfa (*Medicago sativa* L.), add significant amounts of N to soil, often increasing with stand age[62]. However, even single-year effects of alfalfa on N status can be significant, as net soil N contribution of 121 kg N ha^{-1} from 'Nitro' alfalfa has been observed in Manitoba[63].

Utilizing crop residues as a feed resource for livestock represents a simple and economically viable management option to improve production efficiencies within integrated crop–livestock systems[15]. For example, grazing plans that utilize corn residue can provide four to five animal unit months of grazing per hectare under favorable weather conditions[64]. Grazing, as opposed to mechanically harvesting residue for feed, has the added advantage of allowing livestock to distribute manure, thereby reducing operating costs associated with manure spreading. As outlined above, livestock manure can be utilized as an important source of plant nutrients, and when applied in appropriate amounts and times during the growing season, can serve to meet crop requirements for N or P while minimizing damage to the environment.

Environmental impacts: notable drawbacks

Despite the attributes briefly outlined above, it is incorrect to assume integrated agricultural systems have only positive effects on the environment. Nutrient management is of central importance to minimize environmental degradation within integrated agricultural systems, and is perhaps the most significant factor where potential drawbacks exist. Manure can be highly variable as a source of plant available nutrients and it is often difficult to ensure application amounts are spatially relevant across variable landscapes[65]. Where excessive manure is applied to cropland, significant accumulation of N, P and salt in soil can occur[44], potentially impairing water quality and soil function[66,67]. Degradation of surface water quality within integrated agricultural systems can be exacerbated by livestock trampling, which can contribute to near-surface soil compaction and decreased infiltration rates if soils are not dry and/or frozen during grazing[64]. Emission of greenhouse gases represents another potential source of environmental degradation from integrated agricultural systems. Although there is a lack of data on greenhouse gas emissions from these systems, results from manure application rate studies suggest nitrous oxide emissions could be significant when application rates are high and water is abundant[68]. While climatic and edaphic factors will play a central role in determining the net effect of integrated agricultural systems on global warming potential, it is conceivable that emissions of nitrous oxide and methane (from soil and ruminant livestock) could offset increases in soil carbon storage.

How the Environment Affects and is Affected by Integrated Agricultural Systems

This paper has examined associations between the environment and integrated agriculture from two different aspects. First, we explored how the environment affects the adoption of integrated agricultural systems. Integrated agricultural systems may be prevalent in areas where a key resource becomes limited (such as water). This trend may be driven by the capacity of integrated agricultural systems to provide greater economic stability in variable conditions. Secondly, we reviewed the impact of integrated agricultural systems on the environment using four different sustainability strategies[38]. This evaluation emphasized the potential of integrated agricultural systems, as represented by integrated crop–livestock systems, to enhance environmental sustainability.

Future conditions for agricultural production are difficult to predict, although it seems increasingly certain that fossil-based resources will become more costly and global climate change will intensify. Constraints of resource availability coupled with the likelihood of increased frequency of severe weather events presents significant challenges to agriculturists seeking to design sustainable agroecosystems.

With these challenges in mind, Kirschenmann[10] deftly outlined the immediate need for developing more integrated, complex and diversified agricultural production systems. Such agricultural production systems would be characterized by a 'mixing' of production enterprises, as specialized production systems would eventually become obsolete with restrictions in fossil-based resources[15]. Integrated agricultural production systems, then, appear to be well suited to meet the challenges that lie ahead for agriculture. Not only can integrated systems capitalize on potential synergies between cropping systems and livestock production, but they could also confer greater agroecosystem resilience under variable weather conditions by improving soil attributes necessary to sustain critical soil functions.

Developing integrated agricultural systems that can respond to these challenges requires a significant shift in thinking. Researchers and producers need to look at the environment as an ally rather than as an adversary, whose constraints must be overcome through technology and inputs. This will also require that we view agricultural outputs not as products or waste, but as a means to enhance, or at the least not damage the agricultural ecosystem.

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Interactions in integrated US agricultural systems: The past, present and future

J. Hendrickson[1,*], G.F. Sassenrath[2], D. Archer[3], J. Hanson[1], and J. Halloran[4]

[1]Northern Great Plains Research Laboratory, USDA-ARS, Box 459, Mandan, ND 58554, USA.
[2]Application and Production Technology Research Unit, Jamie Whitten Delta States Research Center, 141 Experiment Station Road, Stoneville, MS 38776, USA.
[3]North Central Soil Conservation Research Laboratory, USDA-ARS, 803 Iowa Avenue, Morris, MN 56267, USA.
[4]New England Plant, Soil and Water Research Laboratory USDA-ARS, Room 21, University of Maine, Orono, ME 04469, USA.
*Corresponding author: hendricj@mandan.ars.usda.gov

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Abstract

During the 20th century, American agriculture underwent dramatic changes. At the beginning, farms were more diverse, dependent on animal traction, on-farm inputs and income and, after initial land grants, nearly independent of government policy. However, external issues, such as government policies, mechanization, fossil fuel costs, increased consolidation and vertical integration of markets and increased societal awareness of the environment and concern with farming practices, have substantially altered the structure of agriculture. These external issues are significant drivers of agriculture and we grouped them into social/political, economic, environmental and technological drivers. Previous papers have examined specific effects of these drivers. Our objective is to examine how these drivers interact and influence today's agricultural systems. We developed four categories: (1) Commodity Crop Production, (2) Supply Chain Livestock Production, (3) Organic Production and (4) Extensive Livestock Production, to describe major current agricultural systems. These categories were developed as major and contrasting systems but do not represent all of American agriculture. Although it is not possible to predict the future, interactions among the various drivers will affect these systems differently. By examining multiple scenarios, we conclude the highly specialized systems (Nos. 1 and 2) are highly vulnerable to future changes, and that developing adaptive capacity is critical for dealing with new uncertainty. Sustainable agricultural systems will need balance among various domains to be able to adapt and survive. We suggest that the concept of dynamic-integrated agricultural systems may be the best way to meet this goal because of its ability to consider multiple goals and flexible producer decision-making.

Key words: dynamic-integrated production systems, economic drivers, social/political drivers, environmental drivers, technological drivers, system adaptability

Introduction

Present-day American agriculture is vastly different from American agriculture at the beginning of the 20th century. Major changes have occurred in the number of farmers, the primary source of their income, the role of government, the technology used and the expectations of consumers and society[1]. These changes have come about from the interaction of multiple factors, which are often largely external to the agricultural system itself.

American agriculture will continue to change in the future. The rate of change will occur more rapidly as farmers, not only in the US but also globally, have increased access to information via improved communication technology such as the Internet. The challenges facing agriculture in the future will be more difficult than in the past. An increase in the world's population to 9 billion people[2], increasing urbanization and expansion of cities[3], rapid human-induced introductions of invasive species[4] and increased emphasis on environmental sustainability will place unprecedented demands on agricultural systems.

Holling[5] described a key component of sustainability as the 'capacity to create, test, and maintain adaptive capacity'. Integrating multiple enterprises into an agricultural operation can enhance the adaptive capacity needed to respond to future challenges. Integrated agriculture may

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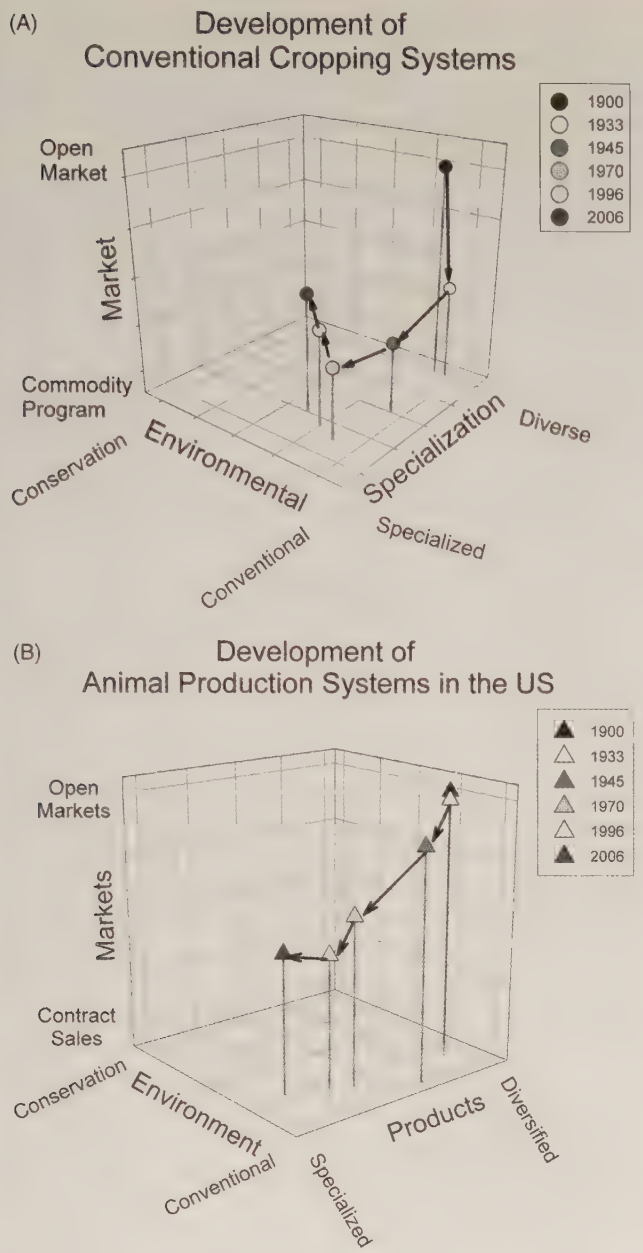

Figure 1. Transitions in conventional production systems in response to economic, social, political, environmental and technological influences. (A) Conventional crop production. (B) Animal production. Except for 1933 and 1996 when specific changes in agricultural policy occurred, year refers to a more general time frame.

well provide the model to develop sustainable agricultural systems in the future. However, to develop these systems, interactions between factors, external and internal to the system, must be understood.

Previous papers in this issue have established a background for a discussion of agricultural production systems[6], and explored the four main drivers shaping agricultural production systems: social/political[7], economics[8], technology[9] and environment[10]. Our objective is to examine how interactions among these drivers have influenced the structure of US agriculture in the past, and how they may shape it in the future.

Development of Current Production Systems

Over the past century, many changes have occurred in agriculture. Potentially the most dramatic of these changes has been to the farm unit itself. The structural evolution of US agriculture can be seen by examining the characteristics of two common production systems, a conventional cropping system and an animal production system, over time (Fig. 1). Farms have tended to become larger, fewer in number and more specialized[1,11]. At the turn of the 20th century, farms were highly diversified, typically including both animal and row-crop production. Increasing specialization since then has reduced the average number of commodities produced per farm from around five in 1900 to just over one in 2002[1]. These structural changes in agriculture have been driven by the interaction of social/political, economic, environmental and technological factors.

Specialization

One fundamental change in the structure of US farms has been increased specialization. A key driver encouraging the shift towards specialization came from US agricultural policy. During the Great Depression, agriculture and rural America was in the most devastating period in recent American history[12]. The economic crisis of the 1930s precipitated the development of modern US agricultural policy in the Agricultural Adjustment Act of 1933[12], designed to address the needs of rural poverty and depressed farm income[8]. The US farm programs increased specialization by supporting only a limited number of commodities[13] (Fig. 1A, 1933). Changes in trade and monetary policy in the 1970s promoted the production of exportable crops and further increased specialization (Fig. 1A, 1970). Changes in the support programs with the Freedom to Farm bill of 1996 increased the planting options available to farmers (Fig. 1A, 1996), although most support still focused on a select few commodity crops.

Specialization on US farms has also been increased by reliance on petroleum-based inputs. An FAO report[14] indicated that cheap resources lead to specialization but restricted resources lead to mixing enterprises. US farmers have relied on relatively cheap fossil fuels for mechanization, pesticides and fertilizers. This reliance has also impacted livestock, such as the beef cattle industry, which relies heavily on fossil-based fuel[15].

Petroleum-based inputs have resulted in dramatically higher yields[16] but have also increased the specialization of agriculture. For example, prior to the adoption of the tractor, at least a portion of the farm's acreage needed to be in forage for feeding draft power[17]. While energy intensity (total farm output per unit of energy use) has declined,

energy costs as a share of total production costs are still high for many crops such as corn and wheat[18]. However, because of increases in fossil-fuel prices, costs of petroleum-based inputs have increased. For example, according to Economic Research Service data[19], N fertilizers have increased in price over 80% since 2000. While increases in petroleum-based input costs may decrease specialization as producers search for crops and livestock requiring fewer inputs, increased demand for biofuels, such as ethanol from corn, may lead to increased specialization as more acres are planted to meet demand.

Advances in technology also helped to increase farm-level specialization. Technology was driven by a fundamental desire to improve yields, reduce costs and reduce the amount of labor needed[8,9]. Refinements in tractor design during the 1920s and 1930s increased the tractor utility, and an acceleration of tractor adoption followed World War II, which increased farm size[11,17] and corresponded with a decline in average number of commodities produced per farm from almost 4.5 in 1945 to under 3 in 1970[1] (Fig. 1A, 1945). Technological enhancements were often focused on program crops, increasing specialization. Economic expenses associated with adoption of technologies often further limited diversification of production operations[20].

Although livestock production was minimally affected by commodity programs, other factors contributed to increasing specialization in these systems. Barkema et al.[21] suggest that food demand and technology have been the driving forces shaping consolidation in the meat industry. Technological advances in engineering systems led to the development of confinement buildings, while improvements in biological technologies led to genetic improvements in livestock, animal feeding and improved disease control, allowing large-scale animal production in small areas[22] (Fig. 1B, 1970). Vertical integration and contracting began in the broiler industry[23] and increased specialization and scale of agricultural production of livestock[1]. Changes in marketing combined with technological innovations have resulted in nearly 100% of broilers and almost 80% of pork being produced in supply chain agricultural systems in 2000[24]. This shift to supply chain livestock production has greatly reduced the diversity of animal production systems (Fig. 1B, 2006).

Markets

A second fundamental change in the farm structure can be seen in the marketing of products. Changes in agricultural policy, marketing concentration and social pressures have interacted to influence today's farm structure. Beginning with the Agricultural Adjustment Act of 1933, the US government sought to protect farm income and control surplus production through price supports and acreage reduction programs[12]. These policies shifted crop sales away from open markets and increased reliance on contract sales through commodity supports (Fig. 1A, 1933). Beginning in the mid-1980s, there was a trend to decouple farm payments from production and move to greater market orientation, which culminated in the 1996 Federal Agricultural Improvement and Reform (FAIR) act[25]. The FAIR act focused on decoupling agricultural payments from production decisions[25] which may eventually open markets for a greater diversity of products (Fig. 1A, 1996).

Consolidation among agricultural input industries and processors developed rapidly during the 1990s. For example, from 1995 to 1998, 68 seed companies were acquired by six life science firms[26]. Many of these acquisitions were driven by the desire of chemical companies to acquire new genetically engineered plant traits[26]. In agricultural processing firms, a similar consolidation has taken place. The CR4 ratio (the amount of a market controlled by the four largest firms) is greater than 70% for corn milling and soybean processing and has increased by 50% in the meat packing industry[27].

As industries consolidate, often in response to cost and technological factors[21,27], production to consumption may be tightly linked through the use of supply chains[24]. Development of meat supply chains has also been enhanced by social pressures from consumers demanding foods that are safe, nutritious, consistent and easy to prepare[23]. In supply chain production, livestock is grown and sold under contract. While this guarantees a market for the product in much the same manner as commodity crop programs, the independent production decisions are removed from the control of the producers, and are instead the purview of major food companies[7]. This has resulted in a shift in many livestock market segments from open markets to contract sales (Fig. 1B, 1970). While the poultry industry has been vertically integrated for some time, other agricultural products are also moving in this direction. The number of hogs sold under some type of contractual arrangement has increased to over 80% in 2001[21]. The emergence of biotechnology may lead to new supply chains in other types of agricultural production[24].

Environmental awareness

Growing awareness of the negative environmental impacts of traditional farming practices and concern for public health and safety have led to the use of more environmentally friendly production practices in both animal and row-crop systems (Fig. 1A, B). For example, soil erosion in the US has declined 40% since 1938, mainly after implementation of government programs aimed at mitigating losses in 1985[28]. Research and development leading to improved knowledge of the impact of agricultural practices on natural resources and implementation of more environmentally friendly production systems have greatly reduced their environmental impact. Over the past 30 years, reduced tillage equipment has replaced more intensive tillage operations on many farms (Fig. 1A, 1970)[29]. Although the primary reasons given by farmers for using reduced tillage has been efficiency, equipment width and speed,

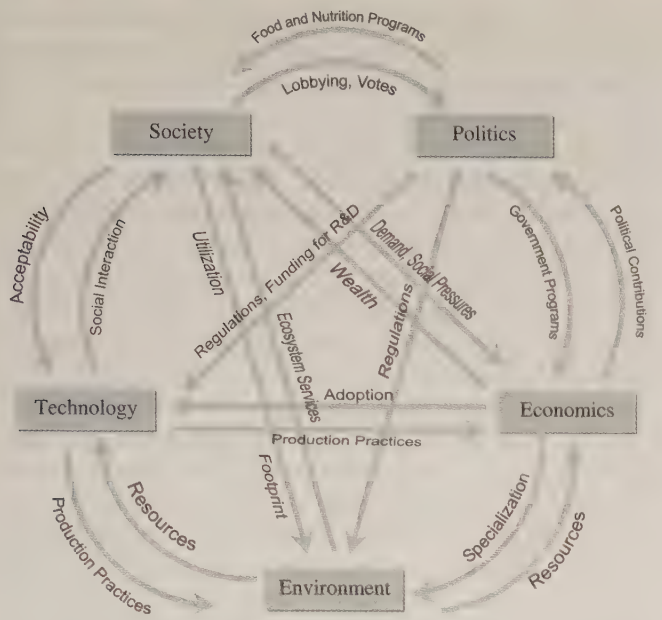

Figure 2. Interactions between social, political, environmental, economical and technical drivers of agricultural production systems.

changes in the farm bill to encourage conservation farming have also promoted the development and adoption of reduced tillage technology[29]. Concerns about the unintended negative environmental consequences of previous farm programs resulted in the introduction of plans in the 1985 Farm Bill to mitigate environmental damage on environmentally sensitive land[30].

Recognition of the potential negative environmental impacts from animal waste has led to regulations aimed at reducing water and air quality impacts and programs to assist producers in implementing waste management practices, increased adoption of waste management practices[31] and research on methods to utilize animal waste products and minimize environmental contamination. Adoption of other conservation practices such as rotational grazing systems, fencing to exclude livestock from sensitive areas and water developments to protect riparian areas have also increased, in part due to an increase in availability of program funding to assist producers by implementing these practices. These practices help reduce soil erosion, improve water quality and improve wildlife habitat on grazing lands[31].

Interactions among Drivers

Current agricultural production systems have been shaped by complex interactions among social, political, economic, environmental and technological drivers (Fig. 2). Societal concerns and demands do not directly affect farmers' choices of production practices, but do exert substantial influence through political and economic pressures. Social drivers impact the farm economy through consumer demand, and impact policy through votes. More direct social pressure is felt on the development and adoption of technology through its acceptance, such as with conservation technologies, or rejection, such as with genetically modified organisms (GMO). The utilization footprint, or amount of resources used by society, directly affects the environment.

Politics impact the development of technology through the availability of funds for research and development, expansion of intellectual property rights, alternative institutional arrangements to promote private–public research cooperation[32] and the adoption of technology through regulations. These political regulations also impact the environment. The political environment has a direct effect on farm economics through federal farm programs. Politics can also affect society through government food and nutritional programs. Producers have used political power by forming private organizations to support specific commodity groups. These private organizations have substantial political clout through lobbying efforts.

Technology interacts with society in two ways: (1) through impacts on the scale of farm production reducing rural populations and (2) increasing communication and awareness of issues at the national and global level. New technology, such as production practices or GMO, can positively or negatively impact the environment. The adoption of technology has a bi-directional interaction with the farm economy. While economic factors often determine adoption of new technology, implementing technology through production practices affects economic risks and returns.

Economics impact and are impacted by other drivers. Halloran and Archer[8] indicated that many future economic trends in the US point toward increasing specialization. For example, cattle slaughter facilities have gotten larger and are located near large feedlots[33]. These plants buy most of their cattle within a 150-mile radius but because of low transportation costs, some cattle come from 650 miles away[21]. With the increase in transportation costs, feedlots may need to be located nearer slaughter facilities. Drabenstott[24] suggested that increased use of supply chains will benefit fewer rural communities and concentrate specific agricultural production into certain geographical regions, similar to what has occurred in the poultry industry. Increased specialization may have a negative effect on both environmental awareness and social factors, such as farmer satisfaction and rural communities. Economics can impact society by creating wealth. Wealth creation can impact society via food cost influences on human health and nutrition, and availability of income for other uses. Halloran and Archer[8] also pointed out the increased demand for ethnic and other food choices in the US as well as social pressures which have altered buying decisions for the three biggest US fast food chains.

The environment also has complex interactions with the other drivers. The environment provides resources which directly affect both economics and technology. Also, increased environmental awareness has impacts on society

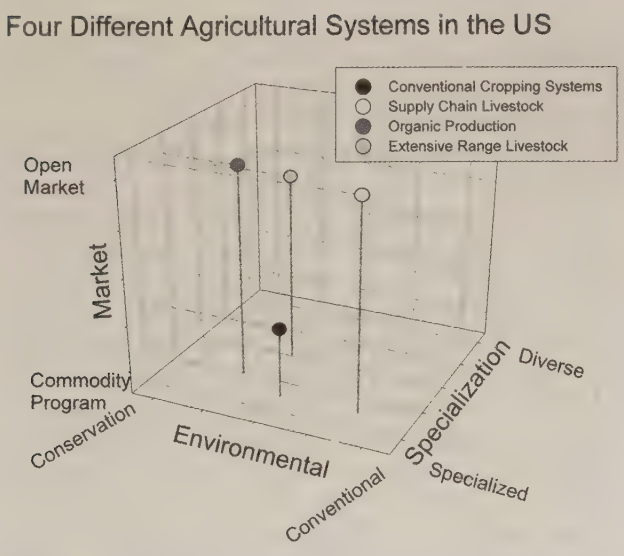

Figure 3. Four major and contrasting agricultural systems in the US. The four systems are conventional cropping systems, supply chain livestock systems, organic production systems and extensive range livestock systems. Descriptions of the systems are provided in the text.

as a whole. Additional social and political pressure has begun to come from the private sector in the establishment of focus groups, such as Ducks Unlimited or the Nature Conservancy, which place a high public emphasis on ecosystem services.

Predominant Production Systems in the US Today

The complex interactions among drivers have resulted in the development of at least four distinct major agricultural production systems in the US (Fig. 3). While these systems do not represent all of US agriculture, they are major and contrasting systems. The focus of US farm policy on relatively few commodities[13] and low margins[7] has produced a highly productive 'Commodity Crop Production' system that relies on high inputs and is heavily influenced by government policy (Fig. 3). This system is highly specialized, often focusing on one or two crops such as corn and soybeans, relies on farm policy for income and risk protection, and is impacted by government policies regarding conservation, such as the Conservation Reserve Program.

Decoupling of livestock and crop production[34] together with increased vertical integration, especially in the meat industry, have led to the development of another production system: 'Supply Chain Livestock Production.' As with crop production, this system is highly specialized, requires high inputs to maintain high productivity levels, and uses contract sales to reduce risk (Fig. 3). Consumer marketing needs and the desire to deliver a consistent product at a minimal cost have been key factors influencing the development of this production system. Markets can have an important influence on the success of this production system as similar products produced at a lower cost get a higher market share.

The growing social awareness of environmental impacts of conventional farming practices and concerns for food safety and consumer health have led to the development of niche markets in specialty crops such as organic production. Social drivers are key factors promoting the increased preference for organic foods[35]. Organic sales have been increasing 20% annually since 1990 and US organic cropland doubled between 1992 and 1997[36]. Changes in policy reflect these social concerns, and further encourage organic production. Moreover, the market 'pull', again responding to social pressures, is further enhancing the demand and markets for organic products[37]. Currently, the largest category of organic production is fresh produce, although organic dairy was the most rapidly growing segment in the 1990s[36]. While organic farming may be a lifestyle choice, economic benefits exist from the premiums often received for organic produce[36]. The rapidly expanding 'Organic Production' system relies on a diverse crop rotation to achieve environmental benefits for the entire system, resulting in greater diversification in organic systems than that seen in other systems (Fig. 3). Organic systems have had a history of marketing directly to the consumer but with the rapid growth of this segment[26] there is increasing concern among traditional growers about the potential industrialization of organic agriculture. As organic foods are more available in traditional supermarkets[36], expanding market opportunities may outweigh these concerns. The result is an emerging division between the philosophically committed small-scale growers and larger-scale operators[38].

'Extensive Range Livestock Grazing' systems are common in the western US. These systems are based on livestock grazing forage produced by rangelands. Although these systems rely on a diverse forage base, the animal component is highly specialized (Fig. 3). The lack of direct government payments in livestock production indicate the importance of markets in determining prices received for products. 'Extensive Range Livestock Grazing' systems are sometimes impacted by government policy in establishing grazing fees on public rangelands[39] as well as the impact of environmental concerns with livestock grazing on western rangelands. Lifestyle is a major concern of producers in 'Extensive Range Livestock Grazing' systems and a study of Colorado ranchers indicated that way of life was a primary motivator for ranchers to continue ranching[40].

The Role of Drivers in Defining Future Production Systems

Agriculturalists are the primary managers of over half of the globally available useable lands[41]. In the US, agriculture (cropland, range and pasture) accounts for 55% of the total land use in the contiguous 48 states[42]. The

extent of land in agriculture means that agriculture can have a large impact on ecosystem services that provide benefits to the larger population[43]. However, the environmental impact of agricultural practices is often unquantified[41] and therefore costs and benefits are not measured. As agriculture intensifies, it can cause changes in ecosystem function[16]. Therefore both agricultural workers and society as a whole have vested interests in maintaining agricultural sustainability.

For US farmers to prosper, agricultural systems must be developed to meet future challenges[11]. However, the future influence and direction of the political/social, economic, environmental and technological drivers are unknown and create difficulties in tailoring agricultural systems to specific, as yet unidentified, challenges. Drivers can positively or negatively influence the ability of current agricultural systems to meet future challenges.

Social drivers

Social concerns are made apparent by changing market demands, as consumers continue to vote with their pocketbooks. In 2000, a majority of families had two incomes[44], and little time for traditional food preparation. This has resulted in increasing amounts of the food budget being spent on convenience foods[1] and dining away from home[45]. This trend will likely remain constant or increase in the future, and amplify the desire for low-cost and consistent products, currently being met by the supply-chain livestock industry.

Environmental concerns have been identified as a leading social factor[7]. Increasing environmental, health and ethical concerns with agricultural production have resulted in rapid growth in organic agricultural systems. In response to social pressure, the three largest US fast food chains require that animals used in their products be produced under humane conditions[8]. These concerns, together with a desire for convenience foods, will probably act in concert to shape agricultural systems in the future. This social pressure will be manifested in either increased pressures in marketing or an increased emphasis in farm legislation, such as regulation of confined animal feeding operations.

Additional social concerns will become apparent with the potential emerging markets in bio-fuels and use of agriculture to produce pharmaceuticals. The Energy Act of 2005 set a requirement of an annual use of 7.5 billion gallons of renewable fuels by 2012[46] and the ethanol industry has expanded its annual capacity by over 2 billion gallons[47].

Global social pressures, seen in the cultural values in trading partners, will also influence markets and agricultural production in the US. Such issues as European trepidation over GMO corn and soybean, demands for better cotton quality, or the Japanese fear of bovine spongiform encephalopathy (BSE) will impact agricultural production. Because of these concerns, better tracking of agricultural products will become a necessity.

Political drivers

Policy impacts technology through funding for research and development, as the areas in which society puts its research dollars make the most progress[48]. The results of social pressures are often translated into political policies, on both a national and global scale. Within the US, USDA expenditures on conservation programs have expanded dramatically since 1983[49] and public support for the protection of agricultural lands from development is growing[50]. In addition, there has been increased interest in the role of agricultural lands in greenhouse gas emissions[51]. This has resulted in the development of mechanisms for agricultural producers to market carbon credits, such as through the Chicago Climate Exchange (http://www.chicagoclimatex.com/) based on conservation agricultural practices.

External social policies also affect US agricultural systems. Agricultural trade issues and domestic agricultural aid were blamed for the collapse of the World Trade Organization talks in July 2006[52]. Most of the direct payments from the US government target few crops, such as corn, soybeans, wheat, rice and cotton[13]. These crops account for 70% of the harvested acreage in the 48 contiguous states in 2002[42]. In 2004, government payments represented 21.9% of the net cash income of farms receiving payments[53]. Loss of these payments would represent a major income loss for farms that receive government payments. External political factors can also affect the sales of non-subsidized products. Japan's concerns over incidents of BSE in the US cattle herd resulted in a 1 billion dollar loss in exports to Japan, although it had little overall impact on beef prices[54]. Still, strong political pressures in major agricultural trading partners could impact the ability of US producers to export their products.

Economic drivers

Future economic trends for US agriculture will be affected by national and global pressures. Halloran and Archer[8] point out that most of the market trends appear to favor larger and more specialized production systems. However, they also indicate that the price premium for organic products is increasing, suggesting that demand is increasing faster than supply. Markets for organic and also sustainable, locally produced, grass-fed and free-range labeled products have also increased[8], suggesting that social concerns of US consumers are being felt in the market place. Increasing demand for bio-fuels could also impact corn and soybean prices, although it is not clear to what extent[46,47].

Internal and external political impacts on US agricultural policy may result in changes to the system of agricultural payments. While the 1996 Farm Bill attempted to decouple agricultural supports from production decisions, it is unclear how farmers are reacting to these changes[8]. Archer et al.[7] point out that the US consumer's demand for

environmental quality may grow faster than food demand which could result in future payments to farmers to manage landscapes rather than produce food, similar to that seen in other countries.

Agriculture is operating in a global environment, which increases the competitive pressures faced by agricultural producers and can negatively impact production. Brazil and Argentina have expanded their share of the global market of corn and soybeans due to a suitable climate, abundant land resources and favorable cost of soybean[55]. Similarly, the loss of much of the US textile industry and increasing demands from off-shore cotton textile plants have increased pressure on American farmers to improve the quality of cotton fiber while reducing the costs of production. Increasing demand for fresh fruits and vegetables year round[56] has led agricultural imports into the US to increase[57].

Conversely, global pressures from increasing populations and improvements in the standard of living in developing countries will increase the demand for food, feed, fuel and fiber, and may allow farmers to capitalize on emerging markets. Internal US need for corn and soybeans may increase if demand for ethanol and bio-diesel grows. This may result in increases in corn and soybean prices either through greater demand[47] or shifts from soybean to corn[46]. Similarly, improvements in the standard of living in other countries may increase the demand for animal protein, raising both animal and feed prices. Such changes may encourage further specialization in animal and crop production systems.

Environmental drivers

One of the primary environmental concerns is the impact of climate change on agriculture and how agriculture can mitigate the impacts of greenhouse gases. Modest global warming has been suggested as being beneficial to agriculture in high-latitude countries such as the US[58] but Reilly et al.[59] pointed out that lower crop prices because of increased productivity could negatively affect producers. Overall, there is a great deal of uncertainty in forecasting impacts of climate change on net ecosystem productivity[60].

In 2001, invasive species in the US were reported to result in losses of $120 billion annually[61]. There are approximately 50,000 non-native species in the US and their number is increasing[62]. Entry of new pests such as Asian soybean rust (*Phakopsora pachyrhizi*) could result in losses of $240 million to $2 billion annually[63]. Other diseases such as bird flu or outbreaks of BSE could devastate the US livestock industry.

Increasing emphasis on ecosystem services may also affect agriculture in the future. Agriculture represents a large percent of the land use in the 48 contiguous states[42] and because of its extent can have a large impact on ecosystem services. Societal emphasis on these services may force agricultural producers to focus more on managing landscapes than on production[7]. However, many farmers are philosophically[64] and economically[20] attached to their current production systems. Changing attitudes toward managing for ecosystem services rather than production may be one of the greatest challenges in the future.

Technological drivers

Technological solutions have historically been developed to address the problems and concerns raised by other drivers and influences of the system. For example, problems with yield limitations led to genetic improvements, while concern for the environment has resulted in development of conservation systems. On the whole, we have faith in the ability of society to expand its knowledge base and invent solutions to the unknown problems of the future.

To address societal concerns and maintain a competitive advantage, farmers frequently feel pressured to incorporate technological advances into their production system[7]. Pressure to implement the latest technology the fastest is real, as the earliest innovators are poised to reap the (potentially) biggest gains[65]. However, they also take the biggest risk should the technology not prove useful.

Improvements in production technology may help address social concerns for the environment. For example, continuous cropping with no-tillage technology resulted in a consistent increase in soil organic carbon while continuous cropping under conventional tillage resulted in soil organic carbon losses[51]. Although, livestock manure from confined feeding operations is a potential source of air and water quality degradation[66], livestock waste has the potential to be used in bio-ethanol production[67] or as a fertilizer, which may reduce fossil-fuel use. Technological advancements will not solve all of the environmental problems related to agriculture. However, within the agricultural system, technology should be considered when developing solutions.

Potentially the greatest impact of future technologies will come from advances in information technologies. These tools allow increasingly rapid exchange of information, reducing lag time between senders and receivers. Information systems greatly expand the capacity for management, sharing of expertise, and the knowledge base available for decision-making. These systems also allow the transfer of scientific information to the end user more directly through decision support tools and expert systems. Unfortunately, increased knowledge gained through tracking of production may reduce personal privacy.

Adaptability

The overriding emphasis in the preceding discussion has been on the uncertainty of future trends. For every possible trend there exist several scenarios as to how that trend could play out. Holling[5] points out the need for adaptability to achieve sustainability. As has been discussed, many current US agricultural systems are highly specialized[1], and

many current economic trends predict future specialization[8]. However, a high degree of specialization reduces the ability of a system to adapt. While US agriculture has been suggested to be resilient in responses to individual factors, such as an outbreak of Asian soybean rust[63], a simultaneous convergence of several trends could be devastating. In addition, managing risk is often managing uncertainty. Highly specialized systems commonly utilize economic methods (e.g. contracting or hedging) rather than biological methods (e.g. crop rotation) to manage risk.

US agricultural production is remarkably diversified, but this diversity is not evident on individual farms. This lack of farm level diversity can affect the sustainability of individual production units and potentially the entire system. A sustainable system will incorporate economic, environmental and social aspects[68], as well as being adaptable[5]. Sustainable agricultural systems at the farm level will need to encompass the three aspects of sustainability while maintaining adaptability. We suggest that to achieve this balance, successful future systems will need to incorporate both economic and biological methods as well as increased access to relevant information. An integrated agricultural system, as defined by Hendrickson et al.[6] may be the best method to achieve sustainability.

However, a large question remains unanswered. If integrated systems can achieve the desired balance and adaptability, why is US agriculture becoming increasingly specialized? We suggest that there are three major factors that have limited the adoption of integrated systems. The first factor is the economics of the farm program. Although the 1996 farm bill decoupled US agriculture to a large degree, the continued use of Loan Deficiency Payments (LDPs) and crop insurance have resulted in a continued lower financial risk in growing program crops. Halloran and Archer[8] pointed out that farmers have continued to grow program crops because of uncertainty in the upcoming farm programs, and Archer et al.[7] indicated that financial returns are low enough that farmers prefer to increase farm size to increase financial income versus the risky approach of trying to increase income on their existing acreage. The continued reliance on crops in the farm program is illustrated by the fact that program crops made up 70% of the harvested cropland in the contiguous 48 states[42].

The second factor is market entry. If a producer wishes to integrate livestock or alternative crops into his system, market entry can be difficult. In the meat industry in particular, vertical integration and the use of contracts can result in barriers to small-scale producers. Drabenstott[24] pointed out that there is also a growing regional specialization. For example, most poultry processing plants are located in the southeastern US[24]. Markets can also pose a barrier to crop producers who wish to grow alternative crops and may have to truck their crops long distances because of the lack of a local infrastructure to handle alternative crops.

The third factor is age demographics. The farm population is aging and the rural communities they depend on are shrinking. The current average age of US farmers is 56.3 years old[69]. As farmers approach retirement, they may not wish to take up the additional management and physical intensity needed in integrated systems. Also, more integrated agricultural systems may require additional labor. A shrinking rural labor pool and/or competition from other non-farm industries may limit producers' ability to get dependable labor for their operations. The increase in off-farm income on many farms[1] may also decrease the family labor pool. Aging farm population may also explain why leasing has increased from 35% in 1950 to 41% in 1997[70]. Because of land tenure insecurity, lesees may be less likely to adopt certain strategies, especially those that impact soil quality. For example, cash renters have been shown to be less likely to adopt conservation practices than are landowners or share renters[70]. The problem then is developing a system that can achieve the goals of sustainability and adaptability while overcoming these obstacles.

Integrated agricultural systems can enhance adaptability and sustainability. Currently, some agricultural producers have integrated through farmer controlled vertical integration. This is in contrast to the current industry vertical integration that is outside of farmers' control. An example can be seen in the catfish industry that requires catfish feed and catfish processing. Because these industries are capital intensive, individual farmers have developed cooperatives to pool economic resources into feed and processing plants. By retaining some control of these secondary industries as part owner, the farmers recoup some of the expense while still maintaining flexibility. Another example is farmer investment in ethanol plants. These plants provide an alternative market for corn as well as providing byproducts for animal feeds. These types of multiple enterprises that contribute to the overall production can be used by farmers to recapture some of the dollars spent on production. By forming cooperatives or partnerships, individual farmers can expand their enterprises, while sharing the risk. This would build an integrated and dynamic production system at a higher level than the individual farm.

In contrast to farmer-controlled vertical integration, Hendrickson et al.[6] suggested the use of dynamic-integrated agricultural systems as a horizontally integrated system which could potentially meet sustainability and adaptability goals. Dynamic-integrated agricultural production systems are agricultural production systems with multiple enterprises managed in a dynamic manner that interact in space and/or time and these interactions result in a synergistic resource transfer among enterprises[6]. This system uses annual and intra-annual decision-making to decide what to grow based on the producers' goals, management concerns and exogenous factors. The dynamic aspect of this concept is a management philosophy that requires management decisions not be predetermined but rather made at the most opportune time with the best available information[6]. Its use of multiple enterprises and tactical decision-making will maintain producer flexibility in a rapidly changing

environment. Because of its emphasis on producers' goals and management concerns, producers can modify it to reflect their current labor and management abilities. A bi-directional flow of information from producers to researchers allows producers to use the best possible information in making management decisions. As technology, and in particular, information technologies, grow, these can be used by producers to ease the management burdens of dynamic systems. These technologies will allow producers faster and more complete and accurate access to information on marketing and management. The challenge is the strategic design of these systems to allow them to respond to changes in an external driver to gain benefits but still maintain sufficient stability[6,71].

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Challenges for maintaining sustainable agricultural systems in the United States

J.D. Hanson[1,*] John Hendrickson[1], and Dave Archer[2]

[1]USDA-ARS, Northern Great Plains Research Laboratory, 1701 10th Ave., S.W., PO Box 459, Mandan, ND 58554, USA.
[2]USDA-ARS, North Central Soil Conservation Research Laboratory, 803 Iowa Ave., Morris, MN 56267, USA.
*Corresponding author: jon@mandan.ars.usda.gov

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Abstract

During the 20th century, US agriculture underwent vast transformations. The number of farmers has decreased, more farmers are relying on off-farm income, agriculture's proportion of the US GDP has declined, and a minority of non-metro counties in the US are farming dependent. Agriculture's evolution will continue and we have identified key trends and future challenges to effectively manage our changing agricultural system. Eight current trends in US agriculture were identified. These included: (1) increased land degradation; (2) competing land uses; (3) focus on single ecosystem service; (4) increase in farm size; (5) movement toward commercialization; (6) genetic engineering; (7) global markets; and (8) changing social structure. Future trends likely to affect agriculture include: (1) diminishing and increasingly volatile farm incomes; (2) reduced government involvement in food regulation; (3) continued transition from farming to agribusiness; (4) land-use will become a major issue; (5) increasing animal protein consumption in the US; (6) increased public input on livestock production practices; (7) increasing urbanization of historically rural US counties; (8) increased public concern over food safety; (9) increased medicinal production from agriculture; (10) new tastes, markets and opportunities will emerge. We further postulated that future challenges facing US agriculture might include: (1) competitive pressures; (2) sustainable development; (3) resource conservation; and (4) research and development. Integrated agricultural systems may be flexible enough to address these challenges. However, robust principles will be needed to design adaptable integrated agricultural systems. We present a nonexclusive list of preliminary principles under the four general categories of (1) economics and economic policies; (2) environmental; (3) social and political; and (4) technological.

Key words: agricultural, trends, challenges, sustainability, ecosystem, service, commercialization

Introduction

The American agricultural community of today is challenged with producing an adequate quantity of healthy food without further damage to the environment. The key issue confronted by agricultural producers in America is that our current methods of food production and handling are not comprehensively environmentally, economically and socially sustainable. If appropriate changes are not made, our ability to produce sufficient quantities of high quality food and maintain an ecological and social environment that can support a growing population will be impaired. Consequently, food production may decline in America with increased imports to support our population.

The application of conventional agricultural practices on our nation's soils can foster an environment for the introduction of a wide variety of destructive pests[1]. These pests are then largely controlled by the use of chemicals. This cycle is particularly evident in the bare-soil monocultures prevalent in much of American agriculture. The results of these cultural practices include, but are not limited to, increased soil erosion, contamination of food and water with nutrients and agrichemicals, and reduction in the number of farms and farmers.

Environmentally sustainable agriculture emphasizes growing complementary crops and animals together in appropriate sequences, keeping the soil covered with growing crops and mulches, including crops and practices that maintain the productivity of the farm, and using detailed knowledge of ecological relationships to reduce the use of purchased inputs such as pesticides and fertilizers to solve problems. Nutrient-use efficiency is a major concern when environmental sustainability is the goal[2]. A range of solutions for improving nutrient-use efficiency exist and

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Table 1. Total area and percent of total land area with severe or very severe human-induced land degradation by region and world total.

Region	Total area	Severe		Very severe	
	Mha	Mha	%	Mha	%
Asia and Pacific	2,899	634	22	207	7
Europe	689	246	36	82	12
North Africa and Near East	1,238	340	27	87	7
North America	1,924	316	16	0	0
North Asia, east of Urals	2,103	364	17	78	4
South and Central America	2,050	458	22	97	5
Sub-Saharan Africa	2,375	146	15	118	10
World	13,491	2,704	20	797	6

Source: FAO AGL.

they range from simple to complex. Government policies, including subsidies; research and technology; and public acceptance of farming practices all combine to create these solutions.

Social and political commitments are required to balance the goals of improved production and profitability, stewardship of the natural resource base and ecological systems, and enhancement of the vitality of rural communities. Such goals must be integrated into various policies and programs, particularly through interagency collaboration, partnerships and outreach[3]. A transition to sustainable practices from conventional agriculture is going to be difficult. It will depend on our ability to integrate technological, economic, social and political aspects of environmental protection and economic development into a unified and consistent management strategy. Agricultural land (cropland and grassland) now rivals forestland in terms of land use and because of anthropogenic impact it is becoming more dominant in environmental management[4]. Although the trend is decreasing as availability of suitable land is becoming more limited, more than 13 million ha^{-1} year globally is converted from some other land use into agriculture. This is driven in part by the need to feed a growing world population and the degradation of existing agricultural lands. Some forecasters are estimating a worldwide population explosion from the current 6.6 billion people to 8 billion people by the year 2020 and to 9.4 billion by 2050. To meet the inevitable soaring worldwide food demands of these people, agriculture will need to produce as much in the next 25 years as it has produced in the past 10,000 years[5].

The doubling of global agricultural food production during the past 35 years was associated with a 6.9-fold increase in nitrogen fertilization, a 3.5-fold increase in phosphorus fertilization, a 1.68-fold increase of irrigated cropland, and a 1.1-fold increase of land in cultivation. Based on linear extrapolation, the anticipated next doubling of global food production would be associated with an approximate 3-fold increase in nitrogen and phosphorus fertilization rates, a doubling of the irrigated land area, and 18% increase in cropland[6].

Current Trends in Agriculture

American agriculture has changed greatly over the past century. From 1930 to 2002 we have seen a decrease in the workforce employed in agriculture from 22 to 2%, a decrease in the percentage of agriculture as an apportionment of total gross domestic product from 7.7 to 0.7%, and an increase in the percentage of farmers working off farm from 30 to 93%[7]. These statistics are indicative of several current trends in US and world agriculture.

Increased land degradation

Human-induced land degradation is a serious global problem. Currently, approximately 25% of the world's, and nearly half of Europe's, total land area is severely or very severely degraded (Table 1). The causes of degradation are poor agricultural practices, overgrazing, deforestation, commercialization and overexploitation of vegetation[8]. As population pressures increase, there may be increased pressure to develop marginal lands for agriculture, which may increase global land degradation.

Competing land uses

Another trend in modern-day American agriculture is that of competing uses for land that prevent conversion of land to agriculture and lead to conversion of one-time agricultural land to urbanized, wildlife or recreational use. Of particular concern is conversion to urban use, which causes permanent losses of often very productive agricultural lands. To accommodate a growing urban population, world cities will need to expand at a rate equivalent to building more than 13 new great cities (of population >5 million) each year, primarily in developing areas of the world[9]. In the contiguous US, urban areas are increasing at a rate of 405,000 to 567,000 ha per year[10]. Urban areas are increasing most rapidly in the Southeastern, Appalachian and Mountain areas of the US (Fig. 1). Land in parks and wildlife areas have increased >300% in the US since 1945 (Fig. 1). Land area in cropland has remained stable since 1945 with the largest increases in the Northern and Southern Plains states largely offset by decreases in Eastern states (Fig. 1).

Focus on single ecosystem service

Farmland increased in the US until 1950[11]. Since then farmland has declined. Farm specialization has become predominant. This has led to a general decline in landscape diversity with negative consequences for provision of ecosystem services. From 1900 to 2000, the number of commodities produced in the US has decreased from about five to just over one per farm (Fig. 2). Currently >60% of the farms in the US produce only one or two commodities and <14% of farms produce four or more commodities

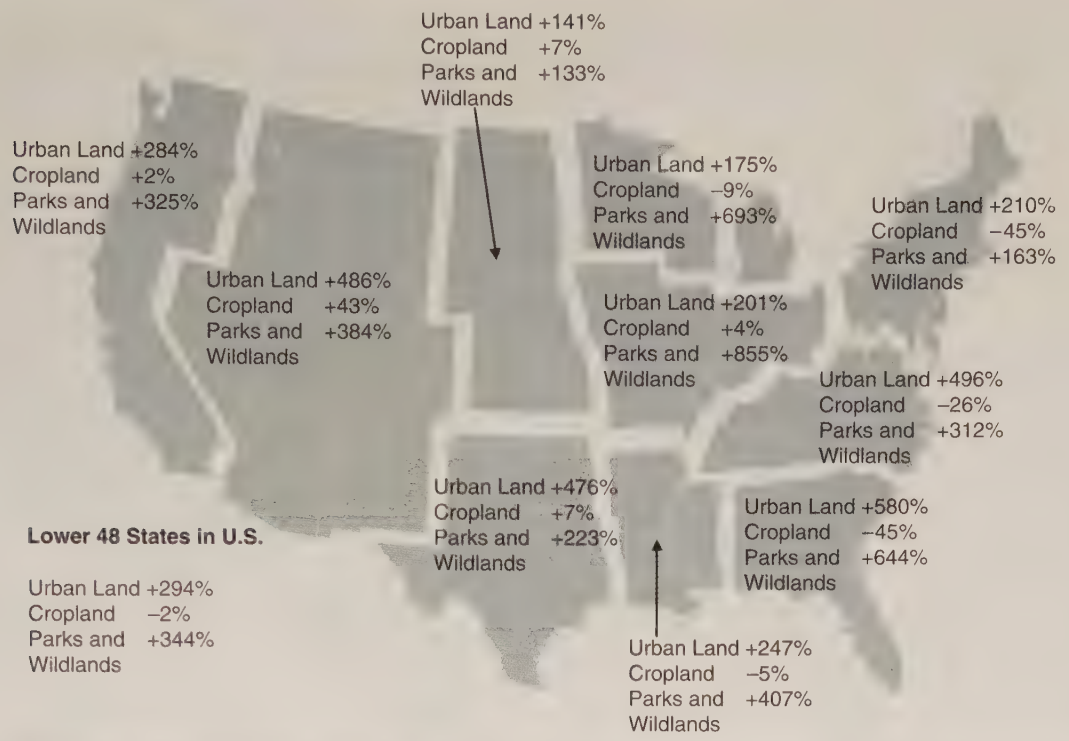

Figure 1. Percentage change in urban land, cropland, and parks and wildlands from 1945 to 2002 for ten different regions of the US and for the lower 48 US States. Source: ERS-USDA Major Land Uses (http://www.ers.usda.gov/Data/MajorLandUses/), updated October 19, 2005, accessed December 2, 2005.

(Table 2). In part, the low average may be due to the inclusion of a large number of retirement and residential /lifestyle farms, which often do not produce any commodities. However, small family farms with high sales, large family farms, and very large family farms, which have the highest average number of commodities per farm, produce fewer than three commodities per farm (Table 2). These farms have more than double the number of commodities compared with limited resource farms. Nearly one-third of limited resource farms specialize in beef cattle production, which generally has low labor requirements (Table 2). Small family farms with high sales, large family farms, and very large family farms may have the economic or labor resources needed to operate multiple commodities. Hoppe and Korb[12] also suggested that the tax code might limit commodity diversity on residential/lifestyle farms. These farms can write-off farm losses especially if they are offset by high off-farm income.

Farmers want to produce the most marketable and cost effective products. Therefore, they logically choose to produce what they perceive as the most marketable commodity. Actively managing for multiple ecosystem services can substantially reduce agriculture's environmental footprint and can be encouraged with production incentives that reward environmental stewardship. These incentives, whether trade-based or policy-based, must be tailored to work in both developed and developing economies to forestall continued environmental degradation and loss of agricultural sustainability[13]. Policies with adequate incentives must be provided for ecosystem services such as clean water and air, plant pollination, disease suppression, habitat development and restoration, and carbon storage.

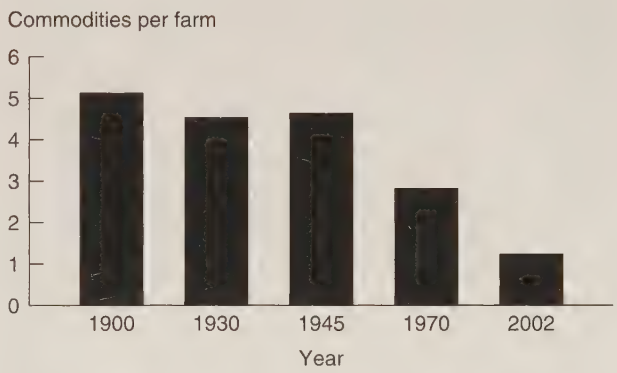

Figure 2. Average number of commodities produced on a US farm from 1900 to 2002. Note: the average number of commodities per farm is a simple average of the number of farms producing different commodities (corn, sorghum, wheat, oats, barley, rice, soybeans, peanuts, alfalfa, cotton, tobacco, sugar beets, potatoes, cattle, pigs, sheep, and chickens) divided by the total number of farms. Modified from Dimitri et al.[7].

Increase in farm size

The number of farms in the US has been decreasing since about 1930, with a corresponding increase in farm size

Table 2. Commodity specialization by farm type in 2001.

Item	Small family farms					Large family farms	Very-large family farms	Non-family farms	All farms
	Limited resource	Retirement	Residential/ lifestyle	Farming-occupation: Low sales	Farming-occupation: High sales				
	Number per farm								
Average number of commodities	1.3	0.9	1.1	1.7	2.6	2.8	2.7	0.9*	1.4
Number of commodities produced[1]	Percentage of group								
No commodities[2]	d	27.7	15.6	4.0**	0	0	0	d	12.8
One commodity	28.2	41.7	44.6	30.3	14.6	14.8	18.4	33.6*	35.7
Two commodities	37.7	24.1	27.0	32.9	21.3	19.9	18.6	14.1**	27.2
Three commodities	d	d	7.7	14.6	20.6	20.8	22.2	3.2*	10.9
Four or more commodities	d	d	5.1	18.2	43.5	44.5	40.8	6.7*	13.4

Source: Hoppe and Korb[12].
[1] Based on 26 commodities or commodity groups.
[2] Includes farms with no production because of drought, other adverse weather, crop, and livestock disease, etc. Also includes farms with all cropland in Conservation Reserve or Wetlands Reserve Programs (CRP and WRP).
* Standard error between 51 and 75% of estimate.
** Standard error between 25 and 50% of estimate.
d, Data suppressed due to insufficient observations.

(Fig. 3). This trend has been most pronounced for states in the North Central and Southern US. In the Western US, the number of farms has increased slightly since 1970. In 1997, the government's definition of a farm changed. According to the new definition, people living in town whose only farm income was a Conservation Reserve Program (CRP) payment as well as people who owned or stabled at least five horses somewhere on the property were counted as farmers. The change resulted in a 17% increase in farms with less than $10,000 in annual income. Therefore, when examining the five-year window from 1992 to 1997 the number of farms decreased by less than 1%. In the 50-year period between 1940 and 1990, farm size more than doubled and the number of farms decreased 67%[7]. Large, very large and nonfamily farms account for 72% of the value of agricultural production in the US, but make up only 10% of the farms[10].

Movement toward commercialization

The commercialization of the American farm has been pronounced over the past several years. As farm numbers have decreased and farm size increased, the food processing industry has also been concentrated into fewer commercial operations. The four-firm concentration ratio (i.e., the sales of the four largest firms as a percentage of total sales) in meatpacking increased from 26% in 1972 to 57% in 1997 with similar increases in other processing industries such as poultry slaughter and soybean processing[14]. A trend is also developing toward supply-chain consolidation[14]. In this type of consolidation, all stages of production, processing and distribution are woven tightly together to ensure reliable, efficient product delivery[15]. Supply chain consolidation predominates in the poultry industry and is beginning in the pork industry. This consolidation has geographic consequences. This concentration further decouples crop and livestock agriculture by shifting the base of operations from near feed production facilities to areas of lower labor costs and closer to key markets. In the pork industry, for example, real growth has not occurred in the Corn Belt but rather in the Southeastern and in the Southern Great Plains areas of the US[15].

Commercialization in the US has replaced ownership and farm control by the farmer with that of the investment community. This has restricted the involvement of the farmer in the decision-making process. In the commercialization model, the predominant decision-making criterion has become the economic bottom-line. We can see and understand more fully the intent of commercialized farming by examining its philosophical bent: (1) nature is a resource to be exploited and variation is to be suppressed; (2) natural resources are not valued except when a necessary expense in production is incurred; (3) progress is equivalent to the evolution of larger farms and depopulation of farm communities; (4) progress is measured primarily by increased material consumption; (5) efficiency is measured by looking at the bottom-line economics; and (6) science is an unbiased enterprise driven by natural forces to produce social good[16]. Certainly, these philosophies are in direct conflict with the development of sustainable agricultural systems. Specifically, we can immediately recognize three areas of concern regarding commercialization of the farming enterprise. First is the ecological concern. Declines in soil productivity, desertification and water pollution, increased scarcity of water, increased and new pests, and rapid global climate change are viewed as negative impacts

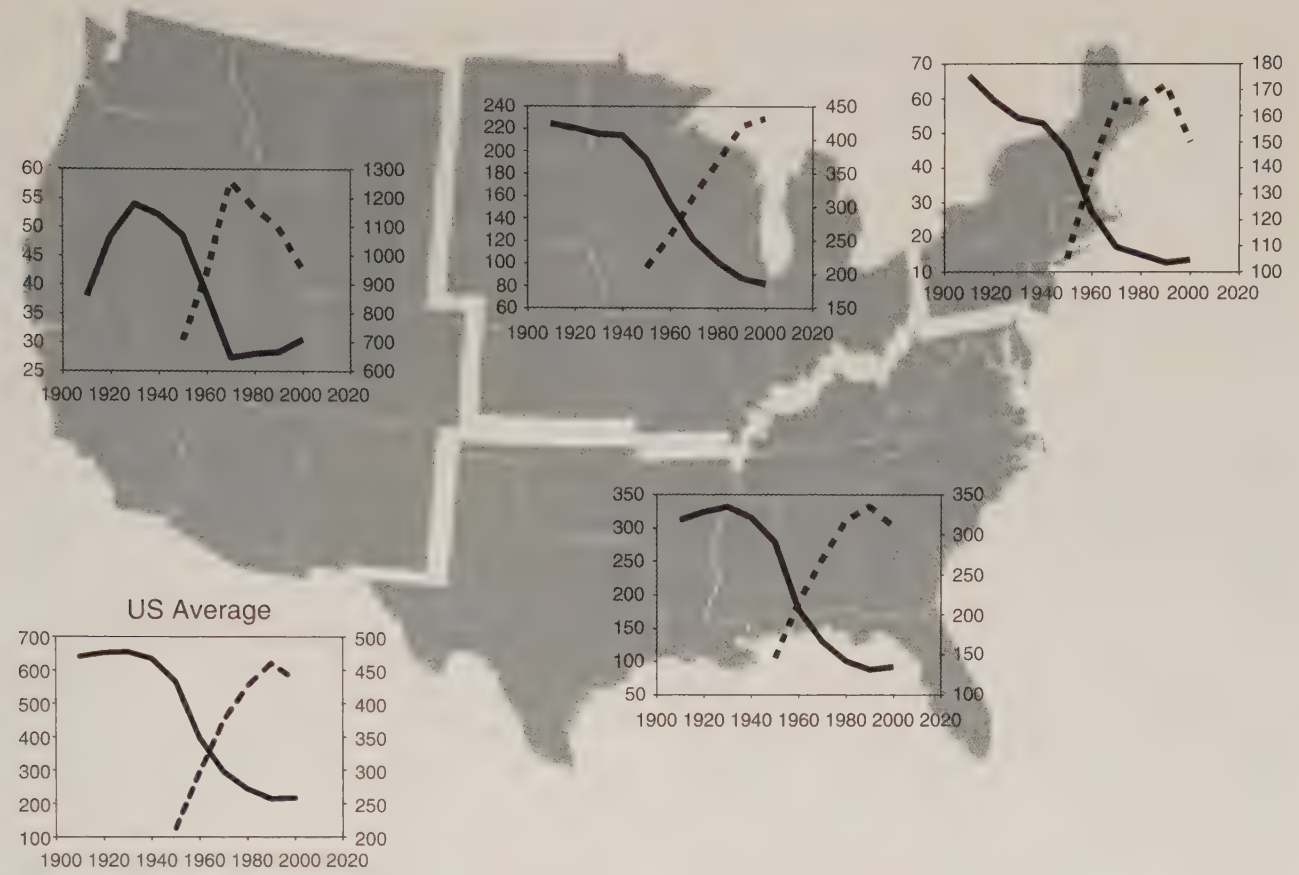

Figure 3. Regional and US average change in farm numbers from 1910 to 2002 and in average farm size from 1945 to 2002. In each graph the *x*-axis is year, left *y*-axis is farm number (10,000) and right *y*-axis is farm size in acres. Solid line is farm number and the dashed line is farm size. Source: NASS, USDA Quick Stats (http://151.121.3.33:8080/QuickStats/PullData_US), accessed December 2, 2005.

only if they have a direct cost to the production system. Secondly are the economic and social concerns. These include increased federal regulation, disparate farmer incomes, disappearance of the mid-sized farm, and urban sprawl. Once again, without a direct cost to the production system, or an overriding social consequence, these changes in agricultural systems are not viewed as losses or problems. Finally are the human health concerns. Included here are the overuse of antibiotics in animal production, nitrate and pesticide contamination of water and food, and the release of other toxic residues into our food and fiber supply[3]. These negative consequences are traditionally handled by reactive rather than proactive approaches.

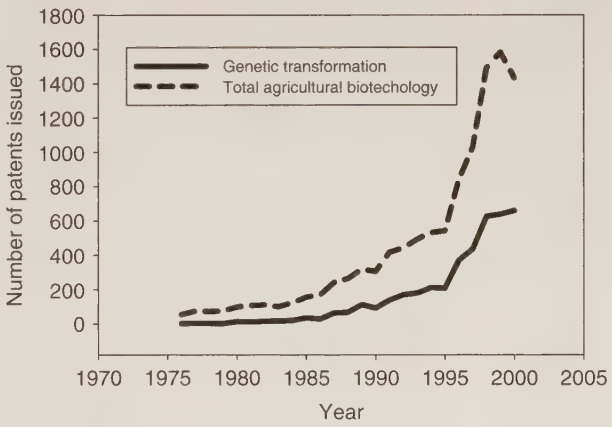

Figure 4. Number of agricultural biotechnology and genetic transformation patents issued by the US patent office since 1975. Source: http://www.ers.usda.gov/Data/AgBiotechIP/Data/Table02_UtilityPatentsByYearTech.html, accessed December 2, 2005.

Genetic engineering

Genetic engineering has become an important technology in US agricultural production. In 2005, 87% of soybean, 79% of cotton and 52% of corn acreage in the US were planted to genetically engineered varieties[17]. Genetic transformation as well as all agricultural biotechnology patents have increased dramatically since 1975 (Fig. 4) and funding has skyrocketed for projects involving the development of genetically modified organisms. However, consolidation has increased in the biotechnology industry since 1995, following the same trends as for other aspects of agricultural production (Fig. 5).

Genetic engineering has been incorporated into current agricultural systems out of a need to overcome several agricultural issues, including the availability of farming land, climatic change, declining water resources, and

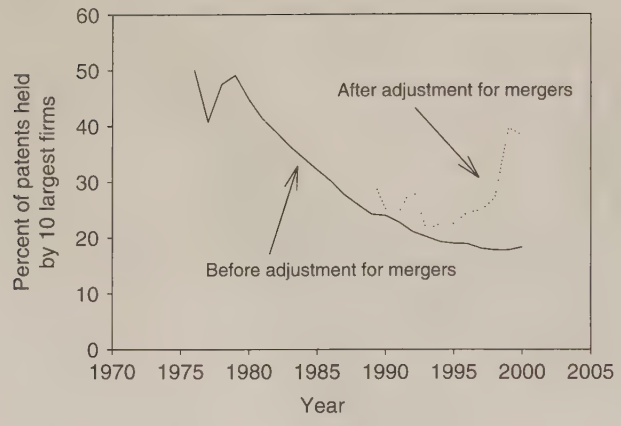

Figure 5. Number of agricultural biotechnology patents issued to the ten largest firms since 1975 with adjustment for consolidation. Figure modified from http://www.ers.usda.gov/Data/AgBiotechIP/Gallery/Graphic4.htm, updated August 26, 2004, accessed December 2, 2005.

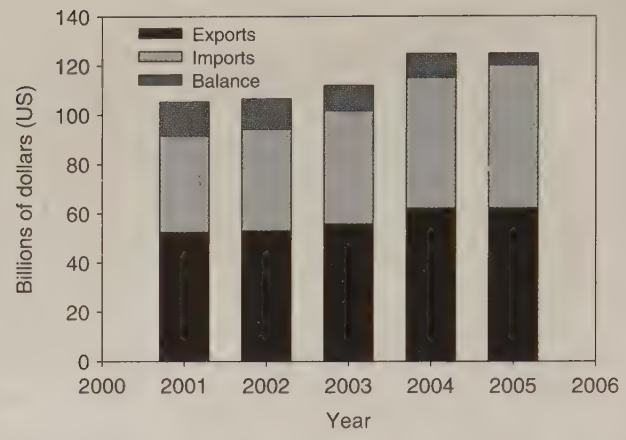

Figure 6. US agricultural exports, imports and trade balance from 2001 to 2005. Figure modified from data in Table 1 of Brooks and Carter[25].

growing demand for food, fiber, fuel, industrial products and products based on 'functional' plants. In perhaps an overly optimistic push, proponents of genetic engineering promise to conquer world hunger. Genetic engineering is based on a mechanistic worldview, which presumes the world operates a lot like a machine. Biotechnology may give us the ability to build, redesign, repair and replace living things. However, careful evaluation of the application and potential overuse of biotechnology in agriculture raises several concerns. First, the risks may outweigh the benefits. The risks involved in biotechnology are not fully understood. Currently there is no adequate method to predetermine the potential impacts of a released genetically modified organism on the ecosystem. Therefore, a precautionary principle should be applied to assure public safety. A new product should not be approved unless there is strong evidence that it is safe and promises important public benefit. The burden of evidence of safety and effectiveness should be the responsibility of the one seeking approval and not the responsibility of the public. Yet for agriculture to continue, knowledge-based and value-added agriculture must become a reality. Resource conservation becomes the most important issue for the future of agriculture. 'The possibilities offered by efficiency developments in conventional seed breeding, supported by gene technology and plant genomic research, will improve the prospects of being able to use our limited natural resources to best effect in the 21st century'[18].

Global markets

Agricultural producers in the US are competing in an increasingly global marketplace. Compared to producers in the US, producers in other countries may be able to produce agricultural commodities cheaper. For example, foreign soybean production has recently exceeded that of the US [19].

Even though agricultural exports remain strong and imports are increasing, the overall US agricultural trade balance has decreased since 2001 (Fig. 6).

The expansion of trade and faster information flow through the internet are converging to alter the worldwide farm and food system. The new farm era is fueled by at least five major issues[20]: (1) finance, technology and information are being democratized; (2) the internet has empowered global information dissemination and increased the speed of information dissemination; (3) the basic human desire for a better life has emerged at the root of globalization; (4) an increased role of world governments to become competitive in the global agricultural marketplace by becoming more efficient and offering higher quality service; and (5) opportunities have evolved through international trade to improve consumer health, provide consumer choices and increase producer income.

Changing social structure

The previous trends have led to a fundamental change in the social structure of US agricultural communities. Agriculturalists in the US are aging at an alarming rate. Since 1974 the number of farmers $\geqslant$65 years old has increased and the number of farmers $\leqslant$35 years old has decreased (Fig. 7). In general, farmers are older in the southern states than in other areas (Fig. 8). There are also age differences between principal production enterprises. Hog and pig farmers had the youngest average age (49.2) and sugar cane, hay crop and other crops had the oldest average age (57.5)[21]. Capital investment can serve as an effective barrier to new farms and limit the types of new, viable enterprises.

Fewer and fewer young people have an interest or opportunity to be directly employed in production agriculture. This subsequently has led to a movement away from rural environments toward urban centers. Corporate farms are being established throughout the US resulting in

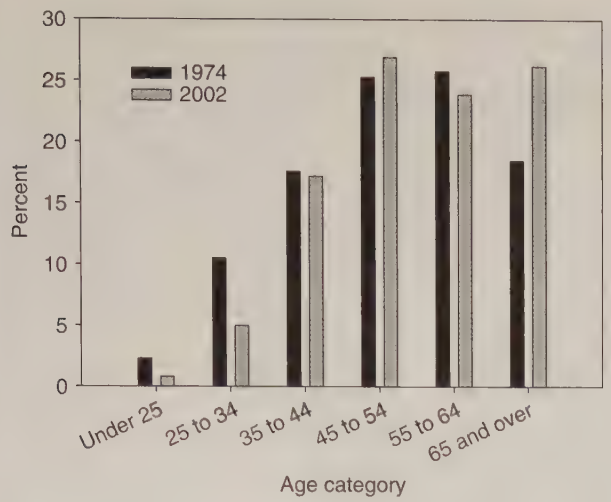

Figure 7. Age demographics for US farmers for the years 1974 and 2002. Figure modified from data in Table 1 of Allen and Harris[21].

a disappearance of the middle-sized farms. The outcome of these combined phenomena is a polarization of the agricultural community.

Future Trends and Challenges in Agriculture

The question now is, 'What does the future have in store for US agriculture?' The driving factors for the near future in agriculture have been put in place. Judging from the outcome of past legislation, the US Farm Bill appears to dictate the crops farmers should produce and thereby drives the production practices employed. Ultimately, this leads to competition between farmers and other programs for federal funds. Increased competition for limited federal funds in combination with international trade issues are likely to result in changes to farm programs. The general population is one or more generations removed from farming. Although the public has less direct connection to agricultural production, there is increased demand for a perceived environmental stewardship. Consumers may not be well informed, but they are discerning. This will bring to the forefront such issues as product identity preservation, designer crops, improved quality (especially in relation to health issues), and organic (reduced use of chemical pesticides and fertilizers) production and commercialization of food. These demands for environmental stewardship and food quality characteristics are likely to shape future agricultural policy and to be reflected in the marketplace. Concurrently, producers are looking for additional economic opportunities and are becoming more market astute. This may cause a movement away from standard crop rotations. This will result in an increase in multiple farm enterprises within a single farm operation, farm ownership in different geographical regions, development of other forms of income-generating operations (i.e., hunting, fishing, site-seeing, etc.) and a flexibility in the use of the products they produce. Agricultural production will no longer be focused solely on the food and feed markets, but will include other outlets such as energy and industrial uses. For example, corn and soybean will not only be used as livestock feed, but will also be sold for the generation of biofuels (ethanol and biodiesel). The use of a biofuel crop within an integrated system adds not only to farm diversity but also is of great importance to the rural community. Selling starch (corn or dry peas) or lignocellulosic material (switchgrass or big bluestem) certainly gives the producer an added economic incentive. But, facilities must be developed to manage and use these materials. Thus, the development of a bioenergy program helps enhance the local economy by providing jobs and an increased tax base.

Because of the bimodalization of farm size and wealth, the middle-sized farm is disappearing. In response to these changes, producers are focusing more on controlling perceived risks. Producers are seeking to increase diversity of marketable products and want an array of options for making the best possible decisions.

Future trends of US agriculture can be inferred from the aforementioned driving factors. These trends are based on the assumption that the conditions that have favored the development of commercialized agriculture will continue. Alternative viewpoints argue that to be sustainable, agriculture must adopt a holistic systems approach that works with the environmental constraints of nature rather than against them[22]. Ten future trends regarding the future of US agriculture are envisioned: (1) there will be diminishing margins of return and increased volatility of farm incomes; (2) the predominant player in food regulation will no longer be the government, but rather international trade organizations or perhaps other non-government organizations; (3) a movement from farming to agribusiness will continue; (4) land-use issues will become major issues; (5) the US consumer will continue to increase animal protein consumption; (6) the public will be increasingly concerned regarding the methods of production and movement of livestock; (7) many historically rural counties in the US will experience increased urbanization; (8) the public concern regarding food safety will increase; (9) the medicalization of agriculture will continue to increase; (10) new and emerging tastes, markets and opportunities will expand[23].

In addition, farms of the future that are owned and run by resident producers will be more diverse, they will exhibit managers who are more innovative and creative, they will be based on stronger notions of economic, environmental, social and political sustainability, and they will contribute more to the well being of the community. Overall, farms of the future will be managed much more intensively. A transition to a sustainable world will depend on our ability to integrate technological, economic, social and political issues of environmental protection and economic development[24]. Whether or not commercialized farms become

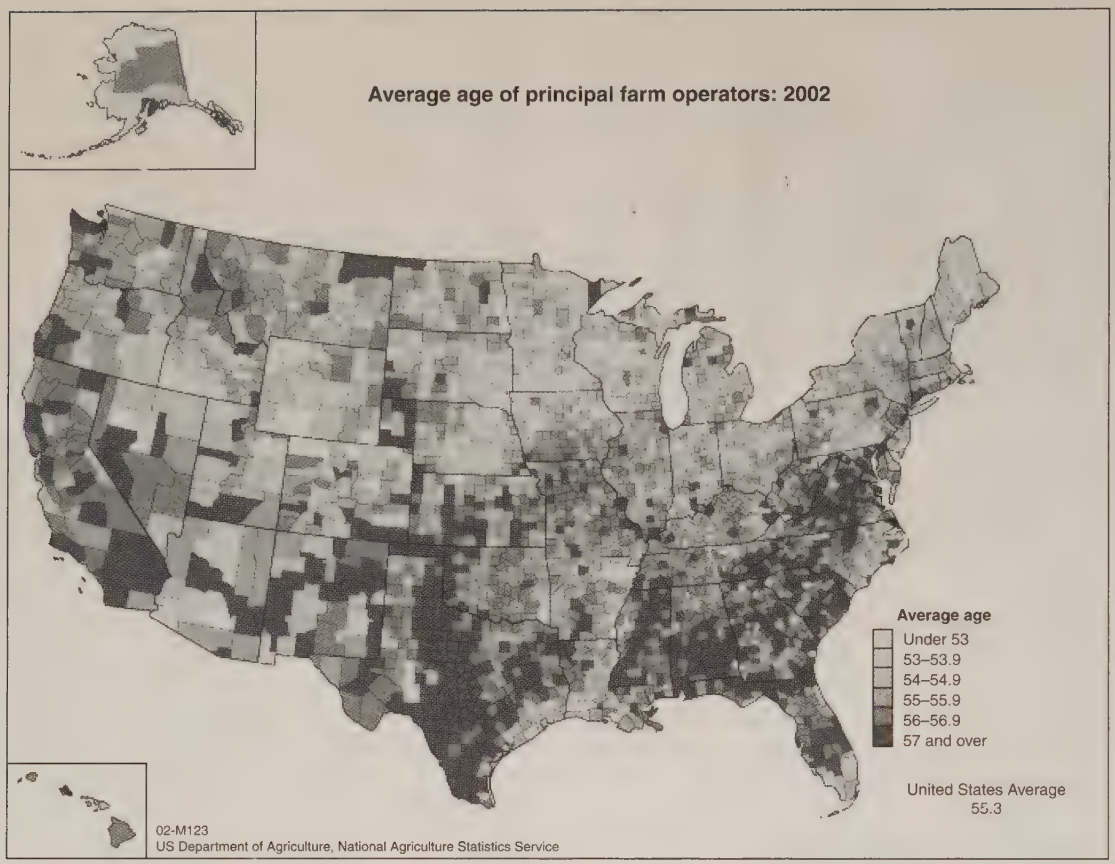

Figure 8. Geographic distribution of average US farmer age in 2002. Figure from Map 1 in Allen and Harris[21].

dominant, US agriculture of tomorrow will face at least four major challenges in completing this transition:

1. Competitive pressures. Future farm policies and management scenarios must be developed to minimize conflicts over land use. Ultimately, land-use decisions should be based on providing the greatest need to the community, and ideally, regulatory and incentive systems will help in the valuation of community benefits. If this is not the case, look for the continued failure of US agricultural systems. In addition, because foreign producers may be able to produce some products cheaper than US farmers, producers must be willing to produce products where they have a competitive advantage.
2. Sustainable development. Agriculture in the US will remain viable only if the environment is protected and enhanced. Thus, sustainability will become the central organizing principle for environmental management. Stated more completely, sustainable development is 'a process of change in which the direction of investment, the orientation of technology, the allocation of resources, and the development and functioning of institutions meet present needs and aspirations without endangering the capacity of natural systems to absorb the effects of human activities, and without compromising the ability of future generations to meet their own needs and aspirations'[25].
3. Resource conservation. Policies must encourage efficient use of land for maximum benefit of the entire population.
4. Research and development. New and improved products must be developed. This should not be restricted to biotechnology and genomics, but also include social and economic development. Social, economic and environmental information will need to be developed and policies implemented to identify, quantify and harmonize the different and often conflicting priorities within the society.

Principles for Meeting Future Challenges

In the past, American agriculture was focused solely on its ability to produce sufficient food, fuel and fiber to meet national and global demands. While productivity will continue to be a major factor in food production systems, increased societal demands for environmentally sound management, the need for rural community viability and a rapidly changing global marketplace have resulted in the relatively rapid evolution of agricultural systems. Integrated agricultural systems may assist in addressing some of these challenges. However, when helping to design and manage these systems, researchers need to be aware of the external influences that may affect these systems. Ludwig

et al. suggested four reasons for overexploitation and frequent collapse of systems that are modified in response to scientific information and consensus, including: (1) wealth or prospect of wealth generates political and social power that is used to drive overexploitation of the system; (2) each system is so unique that comparisons between systems are impossible, therefore one's ability to manipulate the system is hampered and the impact of those manipulations is unpredictable; (3) natural variation masks arising problems and even potential system collapse until it is too late to correct the problem; and (4) assigning causes to past events is problematical, future events are not predicted well, and even well-meaning attempts to exploit the system responsibly may lead to disastrous consequences[26]. By considering these factors, perhaps the paralysis that so frequently occurs and prevents proactive adjustments to conserve needed resources can be overcome.

Yet, in the pursuit of sustainable agricultural systems, it would be useful to identify guiding principles by which they may be developed. Ideally, these principles would facilitate the development of sustainable systems without a change of ownership or bankruptcy. These principles should represent 'fundamental truths' that are common to all sustainable systems. By analyzing external influences on agricultural systems, a preliminary set of principles for integrated and dynamic agricultural systems is proposed below. These principles are organized into four categories, and are presented as a starting point with the idea that they may be tested and modified.

Economics and economic policies

- Bigger is not necessarily better.
- As farm size goes up, the number of farmers decreases.
- The commercial agricultural model does not lead to sustainability.
- Corporate production contracts result in dependent 'corporate farm hands'.
- Economic efficiency must be balanced by regional economic concerns. When efficiency losses are not too great, recycling farm income through the local community will strengthen the community, which will in turn strengthen local farms.

Environmental

- Serious consideration of limited natural resources, efficient and judicious use of nonrenewable resources, and care for the environment are critical to the health of the ecosystem and our own well-being.
- Zero waste is an appropriate goal for managed agroecosystems.
- Streamlining processes and reusing materials will result in zero waste.
- Relying increasingly more on renewable resources for energy will reduce or eliminate agricultural dependency on fossil fuels.
- Reducing consumption of animal protein and food in general will relieve the burden on available global resources.
- Managers should adapt farm production to the environment rather than attempt to adapt the environment to farm production practices.

Social and political

- Through the efficient use of space, increased conservation of materials and energy resources, and reduced transportation, sustainable communities can be developed.
- Through more efficient administration and planning, ecological living conditions that are more economically and socially desirable can be developed.
- Consumerism is not sustainable.
- The principle of sustainable agriculture must be included as a component for developing sustainable communities.
- Regional cooperation between farmers and other relevant stakeholders is necessary for sustainable landscape development.
- To value and manage agricultural landscapes for multiple ecological services the integration of ecological and socioeconomic research, policy innovation and public education is required.

Technological

- New technologies can be useful for solving environmental problems while increasing economic productivity.
- For US agriculture to continue along a sustainable path of economic development, further production increases must be generated by technologies that are profitable, environmentally benign and not socially destructive.
- Markets must be developed that value environmental attributes to speed the adoption of 'sustainable or green technologies'.
- Even when technologies are profitable, barriers to adopting new practices can limit the effectiveness of green technologies.
- Technology should be selected for appropriateness rather than simply for the sake of technology.
- Use of off-farm inputs can be reduced by increasing the level of management.

Summary

Agriculture, as we know it, is destined to undergo remarkable change. The US agricultural community will face many new and difficult challenges in the years to come. The global marketplace is already dictating agricultural policy and subsequent production in the US. New policies need to be developed to encourage the development of integrated-dynamic agricultural systems. These systems can ultimately assist land managers to develop new

and improved sustainable land-use strategies to the benefit of generations to come.

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Book Reviews

Civic Agriculture: Reconnecting Farm, Food, and Community. By Thomas Lyson. 2004. University Press of New England, Lebanon, NH. 136 pp. US$16.95, ISBN 1–58465–414–7, paper back.

Written as part of the Tufts University series on civil society, 'Civic Agriculture' is rural sociologist Thomas Lyson's conceptual language for identifying and analyzing the recent emergence and growth in the US of one 'new agriculture'. Grounded in community-based food production and sales, civic agriculture—according to the author—not only meets consumer demands for fresh, safe, and locally produced foods but also 'creates jobs, encourages entrepreneurship, and strengthens community identity'. Expressed in such enterprises as farmers' markets, community gardens, community supported agriculture (CSA), and farm-to-school programs, Lyson positions civic agriculture as a viable alternative and counter-strategy to the socially, economically, and environmentally destructive practices he associates with the conventional industrialized and globalizing food system, particularly the other 'new agriculture' that is based in biotechnology and genetically modified plants and animals.

Chapter 1 expands the framing of this country's agricultural structure as increasingly dualistic, with civic agriculture on one end and industrial agriculture on the other. Driven by 'neo-classical/market-driven economics', the industrial end is characterized by commodification of a narrow range of bulk food products, concentration in the food processing and retailing sectors, and a systematic distancing and uncoupling of food production from its consumption. Chapter 2 provides a concise and quite excellent history of how the form of American agriculture shifted from a local, self-sufficient system of food production and distribution in the late eighteenth and mid-nineteenth centuries to its current industrially organized, corporately dominated, and globally managed form. This analysis is significantly aided by the use of conceptual tools that are well grounded in the social science literature: de-skilling and technological replacement of labor, commodification and the rationalization of economic relationships, externalizing and diminishing the significance of non-market relationships, technological treadmills, corporate food-chain clusters, interlocking corporate directorships, and oligopolistic pricing and profit taking.

Chapters 3 and 4 continue the interplay between history and socio-economic forces and formations. Highlighted are several long-term trends that have shaped (and reflected) America's food and agricultural system over the past century: (1) decline in the number of 'farming occupation' farms; (2) concentration and consolidation of food production in a small number of very large farms; (3) specialization of food commodity production by region of the country; and (4) severance of the linkages between local food raising and eating. The analytical discussion is aided considerably by a selection of very readable and informative data tables highlighting the historical erosion of farm numbers and concomitant increase in farm size and dependence on purchased inputs, a parallel erosion of enterprise diversity on farms and resulting concentration by farm and region of the system's primary food commodities, a third historical erosion of the share of food consumers' dollars going to the farming sector of the food system and, appropriately for this book, a listing of the world's largest food processing and retailing corporations at the beginning of the twenty-first century. Examples and stories also illuminate the analysis. My favorite is the saga of the Green Giant food company. Begun at the turn of the twentieth century as a regional vegetable-processing company in Minnesota, Green Giant tumbled through the next hundred years being sold, divested, and re-sold by no less than four major multinational food companies, coming to rest at the turn of the next century back in Minnesota as only a brand name acquired by General Mills.

Chapters 5 through 7 focus on the civic agriculture end of the food system duality. Consistent with the book's style and strengths, the analysis is grounded in theoretical and conceptual tools that the author revives from less-well-known voices from the social science literature ... to the rich benefit of readers across a wide spectrum of experience with these issues. The first voices speak about the strengths and advantages of collective or community problem solving relative to individual problem solving and competition. As Lyson indicates, 'Community problem solving rather than individual competition is the foundation of civic agriculture'. Excellent conceptual tables in Chapter 5, describing alternative models of agricultural development, show that these alternative strategic orientations are not only deeply rooted in different philosophical approaches (pragmatism versus neo-classical economics) but also correlate with quite different approaches to scientific analysis, organizational models, political processes, and notions regarding social change.

Amplified are the voices of a group of social scientists working under commissions from the US Congress in the post-Second World War 1940s. Focusing on the relationship between the concentration of economic power at the community level and the social and economic well-being of local residents, the commissioned scientific studies showed quite clearly that communities whose economic bases were

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composed of many, locally owned firms manifested higher levels of well-being than communities where the economic base was dominated by large, absentee-owned firms. Sociologists C. Wright Mills and Melville Ulmer discovered these patterns with regard to non-agriculturally related communities in three eastern states. Anthropologist Walter Goldschmidt found similar patterns of community well-being associated with agriculturally dependent communities in California, one surrounded by a diversity of smaller farms and the other surrounded by large-scale, corporately controlled farming enterprises.

This fundamental insight regarding the importance for community well-being of a diversified, local economic structure sets the direction for the rest of the argument regarding the capacity and value of civic agriculture. Pivotal to civic engagement is the role of an 'economically independent middle class' that provides leadership for a range of networked and collective community problem-solving and community-building activities. Examples of the products of independent farmers networking among themselves and with other community actors are discussed in Chapter 6 under such civic agriculture headings as specialized agricultural production districts, community-supported farming, restaurant agriculture, community gardens, urban agriculture, farmers' markets, and farm-to-school programs.

What is the future for civic agriculture? Lyson is both realistic and optimistic. He recognizes that in its current state of development, civic agriculture does not represent a significant economic challenge to the conventional agricultural and food system. Given the power of its principles, he does envision a time, however, when forms of civic agriculture may generate sufficient economic and political power 'to mute the more socially and environmentally destructive manifestations of the global marketplace'. This vision is grounded in a well-argued premise that civic agricultural enterprises can be significant participants in larger community-based, industrial/production districts and strategies around which modern, technologically sophisticated economies can be organized. Community-oriented economies spring from quite different development models than do corporate-oriented economies. Such models open up opportunities to increase the scale of civic agricultural enterprises to regionally identified, values-based food supply chains that engage midsize farms, ranches and regional food processors, use significant amounts of farmland, spur regional policy initiatives, and supply regional supermarkets as well as local farmers' markets. Given the increasing shakiness of the policy, petroleum, and security supports under the globalized commodity food system, Lyson's civic agriculture in its current and expanded forms looks increasingly attractive.

George 'Steve' Stevenson, Senior Scientist, University of Wisconsin-Madison, and Associate Director, Center for Integrated Agricultural Systems, College of Agricultural and Life Sciences, University of Wisconsin-Madison, USA.
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Agroecology in Action: Extending Alternative Agriculture through Social Networks (Food, Health, and the Environment). By Keith Douglas Warner. Forward by Fred Kirschenmann. 2007. The MIT Press, Massachusetts Institute of Technology, Cambridge, MA 02142, USA. 291 p. $25. ISBN 0262731800, paperback.

Keith Douglas Warner's *Agroecology in Action: Extending Alternative Agriculture through Social Networks* reconciles two disparate fields—agroecological farm practices and appropriate support systems. He presents a social networking model for creating a more sustainable agriculture through new developments in agroecology. The author asserts that '[a]groecology cannot be transferred as a technological package. It can only be facilitated by social learning' (p. 224). University professionals in many colleges of agriculture work in a system in which even the minimal type of outreach expressed through 'technology transfer' type extension has been eclipsed by agribusiness. But in the context of advocating an agri-food system that rejects agrichemicals, farm concentration and intensive monoculture row crops, Warner suggests we must also reject a top-down method of disseminating information. The adoption of agroecological practices is best encouraged by first-hand knowledge of neighboring farmers' success with these strategies, which is why social learning is so essential to its facilitation. Warner describes this process in a series of case studies.

This work emphasizes speaking about agroecological practices to conventional farmers, not to the choir. It is a welcome approach, and difficult to find in work on alternative agriculture that has come out of California in recent years, much of which has a limited relevance due to that state's favorable biophysical attributes and a cultural climate that is conducive to alternative agriculture. Warner accomplishes this broader relevancy by situating agroecology as a compilation of practices amenable to conventional agricultural structures, rather than as a complete and disparate sustainable system. He thus narrates the efforts of wine grape and almond growers in California, Wisconsin potato farmers, and their many allies who have developed networks sharing ecologically appropriate production practices as well as economically profitable approaches to branding those practices.

The first chapter posits healthy ecological systems as a public good. Warner draws from Rachel Carson's *Silent Spring* as he briefly describes some of the harmful environmental impacts perpetrated by industrial agriculture. He then describes the potential and growing role of agroecology in ameliorating these harms. He introduces Science and Technology Studies (STS) and Bruno Latour's circulatory system of science as the basis for his own model of 'interactions between components of a farming system and farm management decisions'. In Warner's 'agroecological partnership model', all participants engage with all four loops of Latour's system, including nature, scientific colleagues, clients and public representation. Collectively,

participants then translate their acquired knowledge for potential implementation by policy-makers.

The second and third chapters describe and criticize conventional agriculture and land-grant extension which supports it, and then contrast it with 'alternative agricultural practices with an alternative extension model' (p. 67). The BIOS model developed by Californian almond growers is posited as the first example-in-action of the agroecological partnership model, and Warner argues persuasively that it 'reveals the imaginary that underlies how agroecology moves from theory into action' (p. 87).

The fourth and fifth chapters introduce in more detail 'The Partners' and 'The Practices'. Warner's agroecological partnership models are made up of growers, extension personnel, and representatives from various science institutions, grower organizations, and public agencies. These individuals and groups ideally learn and share knowledge about the potential for the ecology of crops, insects, nutrients, water, soil and technologies to facilitate agricultural production and on-farm sustainability. Warner claims that 'the agroecological partnership model is a socially created mental model, oppositional to mainstream agricultural science, guided by the belief that alternative agriculture is possible' (p. 78). It seems then, there may be a gap between conventional partners and oppositional practices. The focus on integrating sustainable practices (cover crops and integrated pest management, for example) into conventional farms is welcome and important. But it may not be realistic to expect conventional farmers to become explicitly opposed to mainstream agricultural science. In the case studies presented, various individuals (sometimes growers, sometimes scientists) become interested in agroecological practices, and network with others to learn more. This does not seem to completely echo the 'mental model' described above. Rather, these networks evolve organically, as individuals become more engaged with each other and with knowledge about the potential of alternative farming practices. While a more uncompromising model of advocacy for agroecology has been an essential push for the development of sustainable farm practices, it is the inclusiveness of Warner's partnership model that is the great strength of his research.

The sixth chapter (Agroecological networks in action) and seventh chapter (Circulating agroecology) present more examples of how these partners and practices come together to form partnerships and share knowledge. These networks have each developed engaging and innovative ways of interacting with and organizing relationships among land-grant universities, their scientists, extension professionals, growers and advocates. The acquisition, enrichment and distribution of knowledge about agroecological science is strengthened by the coupling of environmental and economic quality, argues Warner. Indeed, it seems logical that farmers (and others in these networks) are more enthusiastic about ecologically beneficial systems that are also economically viable. As argued in the final chapter, 'Public mobilization', the best size for the agroecological partnership model is regional—too small and the network lacks resources and influence, too large and the network lacks incentive. It is mid-sized farms and networks of farmers, researchers and facilitators, which are struggling to find a sustainable place in the economy and in the environment, and so are best suited to build and grow agroecological models.

Having established the potential for agroecological networks to transform less-dynamic scientific dissemination models as well as on-farm practices, Warner concludes with three policy recommendations. First, he asks the public to insist that 'land-grant universities provide the kind of science to support the agro-environmental leadership that society needs'. Unfortunately, he envisions this as taking place in specific sustainable agriculture programs. It seems that agroecology could be advanced more effectively, if land-grant colleges were to support this kind of science in its mainstream agronomy departments. If agroecology is to displace input-intensive agriculture, it must not be relegated to an 'alternative agriculture' program—it must be central to the philosophy of the college. Warner's final recommendations are that the federal crop subsidy program be replaced with 'public support for land stewardship' and that the U.S. Congress 'create a comprehensive agro-environmental policy and fund agroecological initiatives' (p. 232). These recommendations for increases in funding are partnered by an implicit suggestion that these types of programs replace traditional crop subsidies. Farm payments remain high because of public perception of the cultural, ecological and economic value of agriculture to the nation. Warner argues that an agroecological model fits this perception more appropriately than do the monoculture, chemical-intensive practices being funded today. Warner encourages the view that sharing agroecological wisdom is a public project that should be taken up by policymakers, farmers, researchers and consumers.

Alissa L. Meyer, Department of Agricultural Economics and Rural Sociology, 301 Armsby Building, The Pennsylvania State University, University Park, PA 16802, USA.
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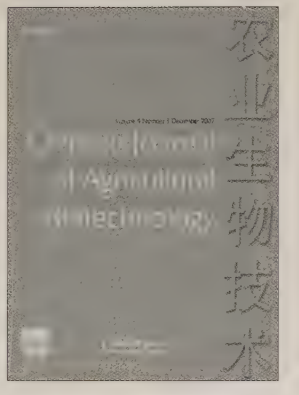

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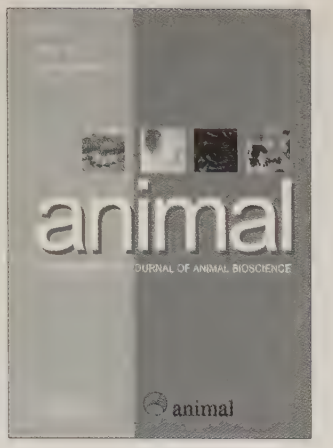

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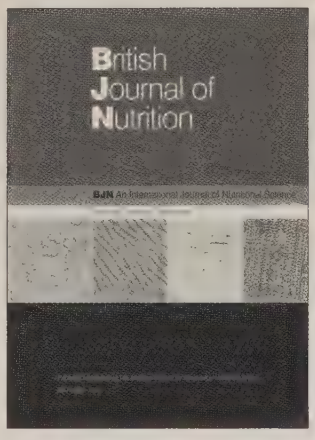

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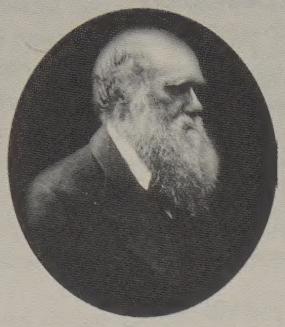

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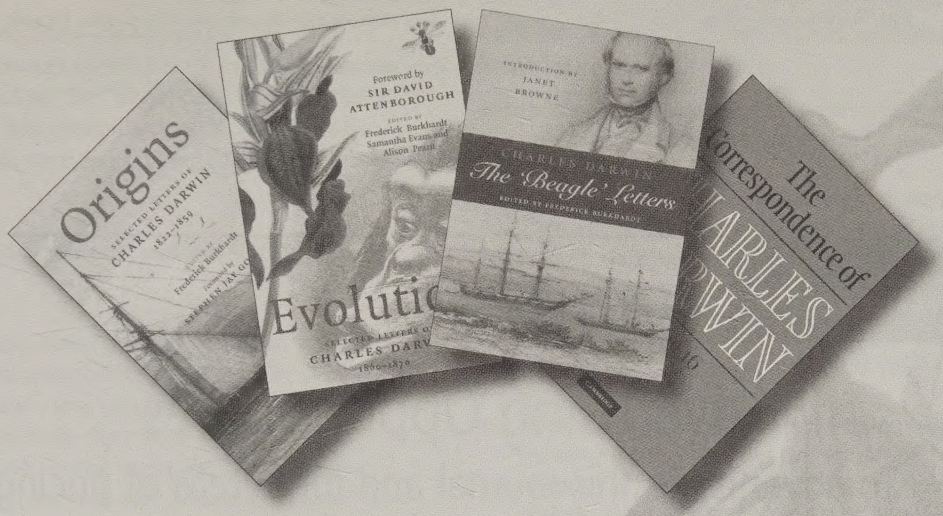

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Editorial
Principles of integrated agricultural systems 263

Research Papers
Principles of integrated agricultural systems: Introduction to processes and definition
John R. Hendrickson, J.D. Hanson, Donald L. Tanaka, and Gretchen Sassenrath 265

Social and political influences on agricultural systems
David W. Archer, Julie Dawson, Urs P. Kreuter, Mary Hendrickson, and John M. Halloran 272

Technology, complexity and change in agricultural production systems
G.F. Sassenrath, P. Heilman, E. Luschei, G.L. Bennett, G. Fitzgerald, P. Klesius, W. Tracy, J.R. Williford, and P.V. Zimba 285

External economic drivers and US agricultural production systems
J.M. Halloran and D.W. Archer 296

Environment and integrated agricultural systems
J.R. Hendrickson, M.A. Liebig, and G. Sassenrath 304

Interactions in integrated US agricultural systems: The past, present and future
J. Hendrickson, G.F. Sassenrath, D. Archer, J. Hanson, and J. Halloran 314

Challenges for maintaining sustainable agricultural systems in the United States
J.D. Hanson, John Hendrickson, and Dave Archer 325

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